PROCEEDINGS

OF THE

AMERICAN PHILOSOPHICAL SOCIETY

HELD AT PHILADELPHIA

FOR

PROMOTING USEFUL KNOWLEDGE.

VOL. XLII.

JANUARY TO DECEMBER,

1903.

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VOL. XLII. JANUARY–APRIL, 1903. No. 172.

Stated Meeting, January 2, 1903.

President WISTAR in the Chair.

The list of donations to the Library was laid on the table and thanks were ordered for them from the Chair.

Messrs. Joseph C. Fraley, Patterson DuBois and Harold Goodwin, the Judges of the annual election for Officers and Councillors, reported that the same had been held on this day, between the hours of 2 and 5 in the afternoon, and that the following named persons were elected, according to the laws, regulations and ordinances of the Society, to be the Officers for the ensuing year:

President.

Edgar F. Smith.

Vice-Presidents.

George F. Barker, Samuel P. Langley, William B. Scott.

Secretaries.

I. Minis Hays, Edwin G. Conklin, Morris Jastrow, Jr., Arthur W. Goodspeed.

Treasurer.

Henry LaBarre Jayne.

Curators.

Charles L. Doolittle, William P. Wilson, Albert H. Smyth.

Councillors to serve for three years.

George R. Morehouse, Patterson DuBois, Ira Remsen, Isaac J. Wistar.

Stated Meeting, January 16, 1903.

President SMITH in the Chair.

The President, on taking the Chair, expressed his thanks for the honor conferred upon him by the Society, and then made some remarks on some recent researches in electro-chemical analysis.

Dr. I. Minis Hays was elected Librarian for the ensuing year.

The Standing Committees for the ensuing year were chosen as follows:

Finance.—Philip C. Garrett, Joel Cook, C. Stuart Patterson.

Publication.—Henry Carey Baird, Joseph Willcox, Amos P. Brown, James W. Holland, Horace Jayne.

Hall.—Harold Goodwin, John Marshall, Frank Miles Day.

Library.—George F. Barker, Albert H. Smyth, J. G. Rosengarten, Edwin G. Conklin, Robert C. H. Brock.

Dr. William W. Keen was elected a Councillor to fill the unexpired term of Prof. Albert H. Smyth, resigned.

Stated Meeting, February 6, 1903.

President SMITH in the Chair.

The list of donations to the Library was laid on the table and thanks were ordered for them from the Chair.

The Secretaries announced the decease of the following members:

Sir George Gabriel Stokes, of Cambridge, Eng., on February 1, 1903, aged 83.

Hon. Fernand Cruz, of Guatemala.

Prof. H. W. Wiley, of Washington, made some remarks on the "Investigations of the Bureau of Chemistry on the Composition and Adulteration of Foods."

Prof. Edgar F. Smith presented a specimen of the metal calcium obtained by electrolysis.

Dr. Samuel G. Dixon made some remarks on the production of tuberculosis by inoculation with tuberculin.

Stated Meeting, February 20, 1903.

President SMITH in the Chair.

A letter was read from Sir Michael Foster, of Cambridge, accepting membership.

The list of donations to the Library was laid on the table and thanks were ordered for them from the Chair.

Dr. A. C. Abbott offered some remarks on "Some of the Problems of the Bacteriologist."

Stated Meeting, March 6, 1903.

President SMITH in the Chair.

A list of the donations to the Library was laid on the table and thanks were ordered for them from the Chair.

The decease of the following members was announced:

James Glaisher, F.R.S., at South Croydon, England, on February 7, 1903, aged 94.

Rear-Admiral William Harkness, U.S.N., at Jersey City, on March 1, 1903, aged 65.

Prof. Angelo Heilprin made some remarks on "The Scientific Aspects of the Pelée Eruptions."

Stated Meeting, March 20, 1903.

President SMITH in the Chair.

A list of the donations to the Library was laid on the table and thanks were ordered for them from the Chair.

The decease was announced of Charles Godfrey Leland, at Florence, Italy, on March 20, 1903, aged 79 years.

Prof. Wilder D. Bancroft, of Cornell University, made some remarks on "The Electrolytic Dissociation Theory, with Application to Medicine and Biology."

General Meeting, April 2, 3 and 4, 1903.

APRIL 2.—MORNING SESSION, 10 A.M.

President SMITH in the Chair.

The President made a brief Address of Welcome.

The following papers were read:

"The Structure of the Corn Grain and Its Relation to Popping," by Prof. Henry Kraemer, of Philadelphia.

"Beaver County (Pa.) Orchids," by Mr. Ira Franklin Mansfield, of Beaver, Pa.

"Development of the English Alphabet," by Prof. Francis A. March, of Easton, Pa.

"Archæology and Mineralogy," by Prof. Paul Haupt, of Baltimore.

"The Activity of Mont Pelée," by Prof. Angelo Heilprin, of Philadelphia.

"The Forward Movement in Plant-Breeding," by Prof. L. H. Bailey, of Ithaca, N. Y.

"Reaction as an Agent in Securing Navigable Depths in River and Harbor Improvements," by Prof. Lewis M. Haupt, of Philadelphia.

AFTERNOON SESSION, 2 P.M.

Vice-President BARKER in the Chair.

The following papers were read:

"The Curtis Steam Turbine," by Mr. W. L. R. Emmet, of Schenectady, N. Y.

"The Principle of Least Work in Mechanics and Its Possible Use in Investigations Regarding the Ether of Space," by Prof. Mansfield Merriman, of Bethlehem, Pa.

"The Nernst Lamp," by Mr. Alexander Jay Wurts, of Pittsburg.

"The Problem of the Trusts," by Mr. C. Stuart Patterson, of Philadelphia.

"On the Dependence of what apparently takes place in Nature, upon what actually occurs in the Universe of Real Existences," by Prof. G. Johnstone Stoney, F.R.S., of London.

EVENING SESSION, 8 P.M.

At the Hall of the Historical Society of Pennsylvania, S. W. Cor. of Locust and Thirteenth Streets.

President SMITH in the Chair.

The following papers were read:

"The President's Address—A Brief History of the Society," by Prof. Edgar F. Smith.

"The Carnegie Institution During the First Year of Its Development," by President Daniel C. Gilman, of Baltimore.

APRIL 3.—MORNING SESSION, 10 A.M.

Vice-President LANGLEY in the Chair.

The following papers were read:

"The Double Star System Σ 518," by Mr. Eric Doolittle, of Philadelphia. Introduced by Prof. M. B. Snyder.

"New Applications of Maclaurin's Series in the Solution of Equations and in the Expansion of Functions," by Prof. P. A. Lambert, of Bethlehem. Introduced by Prof. C. L. Doolittle.

"The Constant of Aberration," by Prof. Charles L. Doolittle, of Philadelphia.

"The Degree of Accuracy of the Newtonian Law of Gravitation," by Prof. Ernest W. Brown, F.R.S., of Haverford, Pa.

"The Mechanical Construction and Use of Logarithms," by Mr. Charles E. Brooks, of Baltimore. Introduced by Prof. George F. Barker.

"The Theory of Assemblages and the Integration of Discontinuous Functions," by Prof. I. J. Schwatt, of Philadelphia. Introduced by Prof. C. L. Doolittle.

"The Franklin Papers in the Library of the American Philosophical Society," by Mr. J. G. Rosengarten, of Philadelphia.

EXECUTIVE SESSION, 12.15 P.M.

President SMITH in the Chair.

Dr. Hays, by unanimous consent, offered the following preamble and resolution, which were unanimously adopted:

"Inasmuch as the two hundredth anniversary of the birth of Benjamin Franklin occurs in January, 1906, it is proper that the American Philosophical Society, which owes its existence to his initiative and to which he gave many long years of faithful service, should take steps to commemorate the occasion in a manner befitting his eminent services to this Society, to science and to the nation. Therefore be it

"*Resolved*, That the President is authorized and directed to appoint a Committee of such number as he shall deem proper to prepare a plan for the appropriate celebration of the bicentennial of the birth of Franklin, and to report the same to this Society."

The President thereupon appointed the following members to constitute the Committee:

Hon. George F. Edmunds, *Chairman*.
Prof. Alexander Agassiz, Boston.
Prest. James B. Angell, Ann Arbor.
Prof. George F. Barker, Philadelphia.
Prof. A. Graham Bell, Washington.
Mr. Andrew Carnegie, New York.
Prof. C. F. Chandler, New York.
Hon. Grover Cleveland, Princeton.
Prest. Charles W. Eliot, Cambridge.
Prest. Daniel C. Gilman, Baltimore.
Prest. Arthur T. Hadley, New Haven.
Provost C. C. Harrison, Philadelphia.
Hon. John Hay, Washington.
Dr. I. Minis Hays, Philadelphia.
Prof. Samuel P. Langley, Washington.
Capt. Alfred T. Mahan, U.S.N.
Dr. S. Weir Mitchell, Philadelphia.
Prof. Simon Newcomb, Washington.
Governor S. W. Pennypacker, Harrisburg.
Prof. E. C. Pickering, Cambridge.
Prof. Michael I. Pupin, New York.
Prest. Ira Remsen, Baltimore.
Prof. John Trowbridge, Cambridge.
Dr. Charles D. Walcott, Washington.
Hon. Andrew D. White, Ithaca.
Prest. Woodrow Wilson, Princeton.

The pending nominations for membership were read and spoken to. The Society then proceeded to ballot for members.

The tellers subsequently reported the election of the following named candidates as members:

Residents of the United States—

Edward E. Barnard, Sc.D., Williams Bay, Wis.
Carl Barus, Ph.D., Providence, R. I.
Franz Boas, Ph.D., New York.

William W. Campbell, Sc.D., Mt. Hamilton, Cal.
Eric Doolittle, Philadelphia.
Basil Lanneau Gildersleeve, LL.D., Baltimore.
Francis Barton Gummere, Ph.D., Haverford, Pa.
Arnold Hague, Washington, D. C.
George William Hill, LL.D., Nyack, N. Y.
William Henry Howell, Ph.D., Baltimore.
Edward W. Morley, Ph.D., Cleveland.
Harmon N. Morse, Ph.D., Baltimore.
Edward Rhoads, Haverford, Pa.
Alfred Stengel, M.D., Philadelphia.
William Trelease, Sc.D., St. Louis.

Foreign residents—
Anton Dohrn, Naples.
Edwin Ray Lankester, LL.D., F.R.S., London.
Sir Henry E. Roscoe, F.R.S., D.C.L., London.
Joseph John Thomson, D.Sc., F.R.S., Cambridge, Eng.
Hugo de Vries, Amsterdam.

Afternoon Session, 2 P.M.

Vice-President Scott in the Chair.

The following papers were read:

"Further Notes on the Santa Cruz Edentates," by Prof. William B. Scott, of Princeton.

"Some Magnetic Properties of Nickel," by Mr. Joseph Wharton, of Philadelphia.

"A New Fresh-Water Molluscan Faunule from the Cretaceous of Montana," by Mr. T. W. Stanton, of Washington. Introduced by Prof. W. B. Scott.

"The Earliest Differentiation of the Egg," by Prof. Edwin G. Conklin, of Philadelphia.

"The Evolution and Distribution of the Proboscidea," by Prof. Henry F. Osborn, of New York.

"An Attempt to Correlate the Marine with the Non-marine

Jurassic and Cretaceous Formations of the Middle West," by Prof. John B. Hatcher, of Pittsburg.

"Hints on the Classification of the Arthropoda, the Group a Polyphyletic One," by Prof. Alpheus S. Packard, of Providence.

"Anatomy of the Floscullariidæ," by Prof. Thomas H. Montgomery, Jr., of Philadelphia.

"A Résumé of the Composition of Petroleum from Different Fields," by Prof. Charles F. Mabery, of Cleveland.

APRIL 4.—MORNING SESSION, 10 A.M.

President SMITH in the Chair.

The following papers were read:

"The Most Insidious Source of Error in Quantitative Chemical Research," by Prof. Theodore W. Richards, of Cambridge, Mass.

"A Further Classification of Economies," by Prof. Lindley Miller Keasbey, of Bryn Mawr, Pa.

"Some Features of the Supernatural as Represented in Elizabethan and Jacobean Plays," by Prof. Felix E. Schelling, of Philadelphia.

"The Hamites and Semites in the Tenth Chapter of Genesis," by Prof. Morris Jastrow, Jr., of Philadelphia.

"The Warfare Against Tuberculosis," by Dr. Mazÿck P. Ravenel, of Philadelphia.

ON A NEW GENUS OF HYDROID JELLY-FISHES.

BY WILLIAM KEITH BROOKS.

(Plate I.)

(*Read April 4, 1902.*)

GENUS DICHOTOMIA.

Diagnosis of the Genus.—Hydroid jelly-fishes with four radial canals which divide dichotomously two, three, four, or more times,

and open into the circular canal by sixteen, thirty-two, or more distal branches; with two sorts of tentacles—hollow ones and solid ones; with a simple mouth and with a single circumferential gonad which extends from the wall of the manubrium on to the radial canals and their branches.

Dichotomia cannoides (Plate I, Figs. 1, 2 and 3).

Diagnosis of the Species.—Bell subcylindrical, somewhat higher than wide, with a conical apex. Manubrium fusiform, widest at about the middle of its upper half. The four radial canals branch dichotomously four (or more?) times. Near the apex the four primary canals arise in two pairs from the ends of a short transverse canal. There are sixteen long hollow tentacles, and about thirty-two (or more?) short solid tentacles. The reproductive organ extends from the wall of the manubrium on to the radial canals and their branches for about half their length.

Special Description.—The four radial canals do not arise independently and directly from the aboral end of the stomach, but in pairs from the ends of a short transverse canal, in such a way that the only planes which divide the jelly-fish into symmetrical halves are the two primary interradial planes. When it is divided in either of these planes each half is itself bilaterally symmetrical, consisting of halves which are reversed copies of each other. In all my larger specimens each of the primary radial canals was divided dichotomously three times, so that there were eight secondary canals, sixteen tertiary and thirty-two terminal branches. In one specimen, which is shown in Fig. 1, one of these terminal canals was again divided into two, so that there were thirty-three instead of thirty-two terminal branches. It is therefore probable that the number of branches continues to increase with the age of the jelly-fish, and that older specimens may have sixty-four or more terminal branches. The subumbrella consists of two strongly contrasted regions: an upper opaque portion which is nearly hemispherical and which contains the arches formed by the reproductive organ on the arched subdivisions of the radial canals, and a lower portion which is cylindrical and transparent. About one-half of the total length of the system of canals is joined to the reproductive organ, which extends from the wall of the manubrium to the radial canals in a system of groined arches, dividing the upper part of the subumbrella into pockets which are closed above, open

below, and equal in number to the terminal branches of the radial canals. All of these pockets open at the same level below, but the sixteen pockets of the fourth set are very shallow, the eight pockets of the third set and the four of the second set are deeper, and the four primary pockets of the first set reach nearly to the apex of the subumbrella. The primary tentacles are stout, hollow, contractile, and when the jelly-fish is swimming they are stiffly extended with their tips coiled into compact spiral whorls. There are sixteen of these tentacles in every specimen that I have examined. The young specimen which is shown in Fig. 2 has sixteen distal radial canals, and a hollow tentacle arises from the circular canal in the plane of each branch of each radial canal. In the older specimen which is shown in Fig. 1 the hollow tentacles are still sixteen in number, although the distal canals are twice as numerous and although the hollow tentacles are now in the radii of dichotomy instead of being, as they are in the younger specimen, in the radii of the distal branches. The solid tentacles are short with little power of extension or contraction; they are usually turned outward and upward over the margin of the bell, and they remind one of the solid tentacles of the Geryonidæ. In all the specimens that I have examined they are equal in number to the distal branches of the radial canals: sixteen in the young jelly-fish shown in Fig. 2, thirty-two in those with thirty-two canals and thirty-three in the one shown in Fig. 1.

Color.—The gonads and the manubrium of old specimens are opaque white. The bell and the subumbrella and the tentacles are nearly colorless. The radial canals, the circular canal and the axes of the hollow tentacles are colored in young specimens by pigment-granules of a brownish-orange.

Size.—The bell is about one-third of an inch high and a little less than one-fourth of an inch in diameter.

Locality.—Several specimens were taken at high tide in an inlet from the open ocean in the Bahama Islands, near Nassau, in 1887, and at Bimini and at Green Turtle, in the Bahama Islands, in 1886 and 1888. It is common and widely distributed among the Bahama Islands.

If the analytical key which Haeckel gives in his *System der Medusen* were to be followed, the genus Dichotomia would belong among the "Leptomedusæ," in the family Cannotidæ, in the subfamily Williadæ, and in or near the genus Proboscidactyla (*System*

der Medusen, p. 158), although it is so different from the Williadæ and in fact from all the "Leptomedusæ" that it may turn out to be a tubularian jelly-fish, or "Anthomedusa." The simple manubrium and mouth, the hollow tentacles and the origin of the gonad in the wall of the manubrium are all points of agreement with the "Anthomedusæ." The solid tentacles have an axis made up of a single row of chorda cells, but as tentacles of this sort are found in undoubted tubularian jelly-fishes they afford no ground for excluding the genus Dichotomia from this group.

Prof. Walcott has described, from the Lower Cambrian of Alabama, certain remarkable fossils (*Fossil Medusæ*, by Charles Doolittle Walcott: Monographs of the United States Geological Survey, xxx, Washington, 1898) which he regards as the remains of Medusæ, and it is worthy of note that if the Medusa which is here described were slightly distorted by pressure the digestive and reproductive organs would exhibit some resemblance to one of the surfaces of some of Walcott's most characteristic types. At his suggestion I made a model in clay of the reproductive organs of Dichotomia in order to exhibit this resemblance, and Fig. 3 was drawn from this model. The resemblance lends additional support to the opinion that the Cambrian fossils are the remains of Medusæ, although it does not indicate that there is any relationship between Dichotomia and the fossils. In fact the resemblance is only superficial. In all the general details of their structure the Cambrian Medusæ must have been very different from the one that is here described.

The notes and drawings for this paper were made in 1888, although I have been forced to delay their publication.

Explanation of Plate I.

Fig. 1. An adult specimen of *Dichotomia cannoides*, enlarged about six diameters. From a drawing made at Nassau, New Providence, in 1886.

Fig. 2. A young specimen, enlarged about twenty diameters. From a drawing made by R. P. Bigelow at Bimini, Bahama Islands, in 1887.

Fig. 3. A clay model of the reproductive organs of Fig. 1.

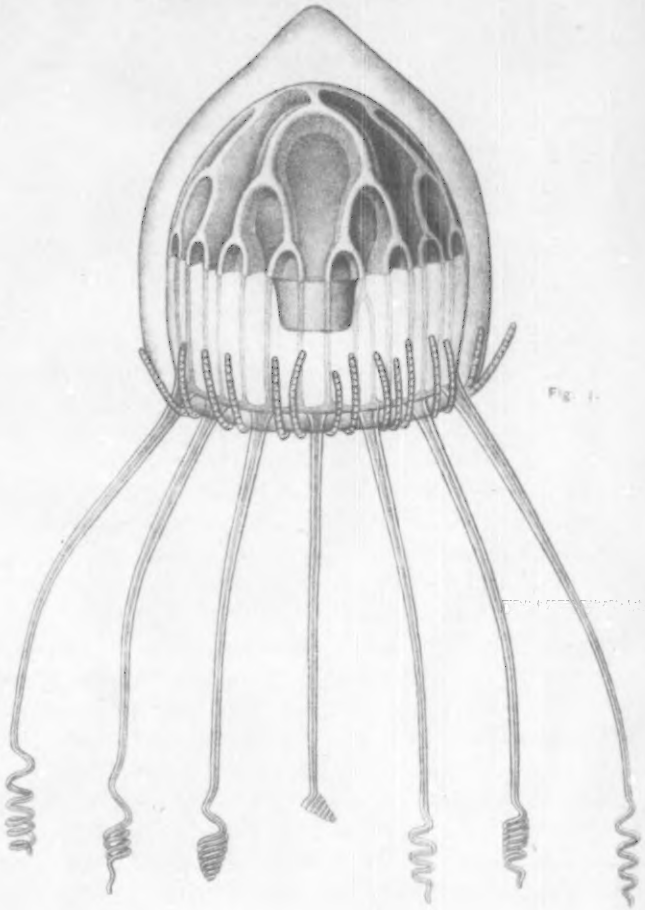

Fig. 1.

Fig. 3

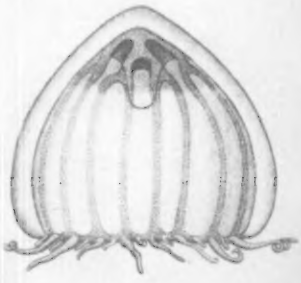

Fig. 2.

DICHOTOMIA CANNOIDES.

TO FACE PAGE 14.

THE PROBLEM OF THE TRUSTS.

BY C. STUART PATTERSON.

(*Read April 2, 1903.*)

The "Trusts" in the popular, though not in the technical acceptation of the term, are the trading corporations, and combinations of such corporations, which control the production or the sale of one or more natural or manufactured products. "Trusts" thus defined do not include banks, nor other merely financial institutions, nor those "Public Service Corporations" which exercise the power of eminent domain, or which occupy public highways for their own purposes, as by laying rails, pipes or conduits.

The "Trusts" are the necessary result of an industrial evolution, whose successive stages have been individual ownership, partnerships, limited partnerships, corporations and combinations of corporations. Partnerships supersede individual ownership because of the advantages of the combination of the capital or services of two or more individuals. Limited partnerships are organized to facilitate the borrowing of capital by giving to the lender a compensation for the use of his money exceeding the current market rate of interest, while limiting his liability to creditors to the amount of the capital loaned. The same advantages of co-operation with limitation of liability, and with added exemption from adverse and discriminating regulation in other States, can be secured by association under "the Boston Trust Device."[1] Corporations are organized to assure continuity of administration; to obtain by the issue of shares, and sometimes bonds, the use of capital contributed by a larger number of persons than can conveniently be brought together as partners; to secure to shareholders exemption from the individual liability *in solido* of partners; and to render the shares negotiable *inter vivos*, and transferable, after the death of the owner, to personal representatives, or legatees, without the intervention of a court of equity in the settlement of partnership accounts.

In recent years the country has enjoyed a degree of material prosperity which has far exceeded the most hopeful anticipations.

[1] *The Financial Chronicle*, Vol. 75, p. 314, article by Richard W. Hale, Esq.

This has come as a result of the growth of legitimate trade, and several causes have been contributing factors of that growth. The demand for labor; our wide expanse of territory; our isolation from the struggle for the balance of power and the wars of Europe; our comparatively light burdens of taxation; and our free institutions, protecting the citizen against arbitrary power and affording full opportunity for the development of individuality, have attracted immigration and furnished recruits to the army of labor. The policy of protection, whose justification is the equalization of the conditions of competition in order that the products of home industry may control the home market, has stimulated manufactures by increasing the profits of manufacturers, has secured higher wages for workingmen than laborers in similar industries receive in other countries, has enabled our workingmen to maintain a higher standard of living, thereby made them more useful citizens, and enabled them in many instances to rise from the ranks of the employés and to become employers. The railways have overcome the disintegrating influences of distance and of conflicting sectional interests. The establishment of the gold standard has given assurance to the world that capital can be invested in our obligations in confidence of a return in money of full purchasing power, and has commanded for the industrial development of the country the surplus capital of the world.

The business of the United States cannot be done to-day by the agencies of the past. The flatboat floating down the stream; the Conestoga wagon floundering through the mud of a country road; the canal-boat dragged by the mules upon the towing path; the small engine; of weak power and low velocity, drawing a few cars of ten or twenty tons' capacity upon a single-track line and the sailing vessel of small tonnage have all had their day. The typical agencies of modern transportation are the four or six track line, the hundred-ton steel freight car, the engine drawing its passenger train at a rate of sixty miles an hour, the electric lines expanding for every city its tributary territory, and the steamship of more than ten thousand tons' capacity.

Discoveries in science and inventions in the arts have created new subjects of commerce, and have made the luxuries of yesterday the necessities of to-day. Great mills now manufacture the goods which formerly were made in individual workshops. Daily and hourly mails, the telegraph and the telephone have brought widely

separated mines and factories within the limits of combined control. Machinery has increased the rapidity, while diminishing the cost, of manufacture and enlarged the possibility of output. In retail trade department stores have absorbed small shops. It is therefore not surprising that industrial organizations should have been, and should be, formed in number and upon a scale larger than ever before to compete, not only for the trade of their own cities and States, but also for the trade of the country, and in many instances for the trade of foreign countries.

Competition in manufacture and trading, when uncontrolled, is wasteful. It results in reducing the selling price of goods below the minimum necessary to give the producer a fair profit; in overproduction in excess of the market demand; in an increase of disbursements unconnected with production or distribution, and connected only with the conduct of competition; in unnecessary cost of transportation of the raw material to distant points of manufacture, when that raw material could be more economically manufactured nearer to its point of supply; and in the unnecessary cost of the transportation of manufactured products to distant markets, when those markets could be more economically supplied from nearer points of manufacture.[1] Uncontrolled competition also results, in the case of weaker competitors, in lowering the standard of production and in placing upon the market inferior grades of goods.

To meet these results of uncontrolled competition, there came into existence pools or agreements between competitors to secure the maintenance of prices by restrictions upon output, or by limitations of sales. Such agreements are clearly contracts in restraint of trade, and as such non-enforceable in law,[2] and being without legal sanction were, like treaties between sovereign states, broken when either party fancied that its interests would be subserved by their abrogation. Intelligent business men then saw that the expanding trade of the country could not be conducted upon lines which, to quote the words of Mr. Schawb,[3] are built upon "the restriction of trade, the increase of prices and the throttling of competition."

They saw also that in manufacture the maximum of efficiency at

[1] *The Trust Problem*, Prof. J. W. Jenks, 1902.

[2] M. R. C. Co. *v.* B. C. Co., 68 Penna. 173; Cummings *v.* U. B. S. Co., 164 New York, 401; Cohen *v.* B. & J. E. Co., 166 N. Y. 292.

[3] Speech to The Bankers' Club, Chicago, 21st December, 1901.

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the minimum of cost can only be accomplished by securing a constant supply of raw material, by making promptly every alteration and improvement in plant and machinery which can effect greater economy in operation, by offering inducements to managers of superior administrative ability, by giving steady employment to workingmen at just wages, by accumulating a reserve fund available for extraordinary expenditures, by increasing the output so as to decrease the cost of production per unit, by expanding trade by creating new avenues for it, and by reducing the price to the consumer, while increasing the profit to the producer. To attain these cost-saving and profit-producing results, combinations of corporations and of properties have been and are being effected, in some cases by the merger and consolidation of existing corporations, and in other cases by the organization of new corporations, to hold and acquire the properties to be consolidated, or to obtain a controlling interest in the shares of the corporations to be combined.

For this there is needed the command of more capital than can be contributed by any one individual or by any group of individuals. Clear-sighted men saw that the prosperity of the country had not only made great fortunes for a comparatively small number of individuals, but had also aggregated in the deposits in the saving funds, in the accumulated reserves of the life insurance companies, and in the deposits in the banks and trust companies a fund of enormous and steadily increasing size, which must necessarily seek profitable investment, and which could be relied upon to make a market for the bonds and shares of corporations with a reasonably probable earning capacity, either by direct investment in those securities or by loaning funds for investment therein; and the appeal was successfully made to these new reserves of loanable funds. Therefore, to-day the capital which is operating the railroads, mining the ore and running the mills of the country is not provided by the rich men of the country, but is the accumulation of the savings of labor.

The test of the investment value of an industrial security is its reasonable probability of a continued earning capacity adequate to the payment of fixed charges and dividends at a rate exceeding that yielded by securities of a higher grade; and that probability of continued earning capacity will be affected by the relation between the cost and the real value of the properties bought for combination by the moderation or extravagance of the compensation given to

the promoters and underwriters, by the soundness of the principles upon which the combination is organized and conducted, and by the freedom of the business from governmental interference. It is not surprising that the number of the industrial organizations and the magnitude of their operations should arouse the public interest and should cause more or less fear as to possible consequences. Every great industrial development has excited such fears. The steam engine, the railways and all forms of labor-saving appliances, from the spinning jenny to the typesetting machine, have seemed n their turn to threaten large additions to the ranks of the unem ployed and heavy losses to different classes of people; and yet, in each case, the result has been the opening of new avenues to employment and a substantial advance in civilization. So to-day no one who is accurately informed as to present industrial conditions can doubt that, because of American financial skill in securing combination of resources and concert of action, the products of industry have been brought to a higher standard, the labor which produces them is better paid than ever before, and the consumer buys them upon relatively more favorable terms.

Concurrently with the organization of corporations with increased capital for production, manufacture and trade, there have come into operation unions of laborers of larger membership and greater activity. Every one ought to concede that it is right that workingmen should receive full and adequate compensation for their labor and should have that legally guarded freedom of contract which will enable them to sell their labor to the best advantage. Every one ought to concede also that workingmen should form associations for the protection of their interests and to secure increases in their wages; but it is not right that those unions should undertake to reduce the mass of workingmen to a low level of mediocrity by means of limitations of the hours of voluntary labor, and by restrictions upon the quantity and quality of work to be performed by the individual laborer; nor is it right that the unions should attempt to monopolize the supply of labor by preventing the employment of non-union laborers. Such limitations and restrictions aggrandize the labor leaders, but they degrade the workingmen; they tend to deprive intelligent, industrious and ambitious workingmen of the opportunity to rise out of the ranks; they diminish that effectiveness of American labor which has been not the least of the causes of the country's industrial supremacy; and

they endanger the continuance of our present prosperity. Combinations of laborers for such purposes are monopolies in restraint of trade.[1] The law should clearly recognize the right of association, but it should also require the incorporation and registration of labor unions in order that there may be legal responsibility for broken contracts; it should, in cases of strikes, impartially enforce law and maintain order, and it should sternly repress any attempt, by whomsoever made and howsoever made, to hinder men in the exercise of their right to work. We find nothing in party platforms, and we hear nothing from executive officers, legislators or candidates for office as to the need of legislative or executive action to curb the power of the labor leaders or to restrain the excesses of their misguided followers. But we hear much of the need of executive and legislative control and regulation of industrial corporations.

It is said, and it is doubtless true, that some industrial organizations are over-capitalized. In considering the capitalization of a corporation, it must be remembered that whatever be the par of a share of stock, that par is not, like the par of a bond, a principal obligation, to be discharged in a certain number of dollars, but it is only the right to an *aliquot* proportion of the net assets of the corporation, and it really represents an amount in dollars, more or less than its par, in proportion as those assets when liquidated shall realize more or less than the aggregate capital of the corporation. The market price expresses the investors' valuation of that representation as affected by the demand for and supply of the particular stock.

The authorized capitalization of a corporation is, in general, determined by the probable cost of the plant, with the addition of the amount of working capital in money necessary for the successful conduct of the business to be transacted, and sometimes with the further addition of a capitalization of the estimated earning capacity of the plant. Obviously, the issued capital should not, in a properly managed corporation, exceed at any time the actual value of the plant and working capital as determined by present and not prospective earning capacity. In other words, there should be no watered stock.

[1] *In re* Debs, 64 Fed. Rep., 724, 745, 755; 158 U. S., 564; *The Law of Contracts in Restraint of Trade, with Special Reference to Trusts*, by George Stuart Patterson, Esq.

It is asserted by no less eminent an authority than the distinguished lawyer who is now the Attorney General of the United States[1] that the necessary effect of "over-capitalization" is to unduly lower the wages of labor and to unduly increase the prices of the product by imposing upon the managers of the corporation the obligation of paying dividends upon the improper excess of capitalization. This view does not seem to be reasonable, for it would obviously be the effort of the managers at all times to keep down the expenses of operation, to make as many sales as possible, and to realize as large prices as possible, without reference to the interest or dividends to be earned or paid, if for no other reason than that of demonstrating the ability of the managers, and this effort would neither increase nor diminish because of the greater or less size of the capitalization. Indeed the only possible influence of a large capitalization upon the prices of the product of the over-capitalized corporation would be in some cases to cause a lowering of such prices, because of the necessity of making realizing sales.

Complaint is made that competing corporations, in order to destroy competition, discriminate in their prices. But competition is industrial warfare. The seller seeks the highest price that he can obtain; the buyer pays as little as he possibly can. When competition is actively conducted, the seller attains his ends, not only by underselling in order to effect a particular sale, but also by carrying his underselling to the extreme limit of driving his competitors out of business and securing for himself complete control of the market. This is done, as Lord Justice Bowen said,[2] from "the instinct of self-advancement and self-protection, which is the very incentive of all trade." . . . . "To say that a man is to trade freely, but that he is to stop short at any act which is designed to attract business to his own shop, would be a strange and impossible counsel of perfection," and to attempt to prohibit it "would probably be as hopeless an endeavor as the experiment of King Canute." You cannot have a real competition which does not compete. Successful commerce buys in the cheapest and sells in the dearest market. Is it proposed that there shall be a general legislative regulation of prices, and if so, what would that amount to?

Among the evils charged against the "Trusts" are an alleged

[1] Speech of Hon. P. C. Knox, Pittsburg, 14 Oct., 1902.

[2] Mogul S. S. Co. *v.* McGregor, 23 Q. B. Div. 598; [1892], C. A. 43.

"insufficient personal responsibility of officers and directors for corporate management." It is enough to say as to this that the laws of some States do, and the laws of all States can, hold corporate managers to a strict responsibility for non-feasance and mal-feasance.

It is also said that these trade organizations have "a tendency to monopoly," but except in the cases of patents and copyrights, and of those who control the sole and exclusive source of supply of a natural product, it is not possible in this day of the world's history to maintain and enforce more than temporarily extortionate prices, for the reason that there is always available a large amount of uninvested capital seeking profitable employment and keenly watching for opportunities of remunerative investment, and therefore intelligent managers of a successful business do not advance prices to a point at which destructive competition will be invited. Prices of commodities are automatically regulated by the law of supply and demand. When, by reason of an apparent permanence of demand and a present inadequacy of the means of supply, prices rise to a level that gives a reasonable assurance of profit to producers, the surplus capital of the world can always be relied upon to augment the means of supply.

It would seem that there is a popular demand for industrial organizations sufficiently strong to overcome repressive legislation. Beginning with the Congressional Anti-Trust law of 2d July, 1890,[1] and the Mississippi statute of the same year,[2] and ending at this time with the sixth section of the United States statute creating the Department of Commerce and Labor, the United States and twenty-nine States and Territories have legislated upon the subject, and two States have deemed it of sufficient importance to place an anti-Trust prohibition in their Constitutions. Some of these State statutes regulate and others of them prohibit, and all of them impose penalties by fine or imprisonment and forfeiture of corporate privileges. Notwithstanding this mass of adverse legislation, industrial corporations have grown and flourished; and yet there is a political clamor for more legislation.

Attempts to regulate trade by legislation are not of new invention. Whenever and wherever there has been an absolute government there have always been attempted restrictions upon trade. In

[1] 26 Stat. 209, c. 467.

[2] c. 36.

mediæval times it was the theory and the practice that it was the "duty and the right of the State to fix hours of labor, rates of wages, prices, times and places of sale and quantities to be sold."[1] The selfish commercial policy of England, intelligently directed to the restraint of colonial trade and manufactures, was the great cause of the War of Independence. When the success of the War of the Revolution had substituted the sovereignty of the people for the supremacy of the Crown, there was naturally a jealousy of governmental power and a determination to guard individual liberty against oppression. The framers of the Constitution of the United States therefore founded the government, not only upon the supremacy of the federal government in the exercise of the powers granted to it, but also and equally upon the independence of the States and the freedom of the citizen. They foresaw the evil effects of an unrestrained exercise of the popular will. They endeavored to establish and make perpetual the reign of law. They crystallized into the Constitution the great principles of free government, and they made it impossible to hastily change that organic law. They declared in express terms the supremacy of the Constitution and the laws made in pursuance thereof; and they created a Supreme Court whose judgments should give effect to that declaration. They united the States in a nation, with full powers of government for all national purposes, but they retained the sovereignty and independence of the States for all purposes of local self-government, and they reserved to the individual citizen as much freedom as is consistent with the enforcement of law and the maintenance of order. While they granted to the United States the power of regulating commerce, they limited the exercise of that power to foreign and interstate commerce.

It is to the States, and not to the United States, that we ought to look for the legislative and administrative regulation of the industrial organizations of the present and the future. The power of the State is ample. A State may create corporations, with or without conditions, and it may authorize a corporation to do any business which an individual may lawfully do. A State may forbid a foreign corporation to do business within its territory; it may permit that business on conditions; and it may, with or without reason, revoke a permission theretofore granted.[2] It may, therefore,

[1] Mrs. Green, *Town Life in the 15th Century*.

[2] W. P. O. Co. *v.* Texas, 177 U. S., 28.

enforce with regard to foreign corporations all, and more than all, the restrictions which it enforces with regard to corporations of its own creation. On the other hand, the United States, save as the domestic government of the District of Columbia and the Territories, cannot even grant a charter of incorporation, except as a means incidental to the exercise by the United States of a power of government,[1] and it can, but only under the power of regulating foreign and interstate commerce, control the operations of a corporation chartered by a State. It does not avail to say that the legislation of a State can have no extra-territorial force, and that in order to have a rule of uniform application throughout the country there must be Congressional legislation, for the conclusive reply is that every State, under the Constitution, is entitled as of right to determine for itself by what agencies and under what conditions commodities shall be manufactured or sold within its territory,[2] subject only to the paramount right of the United States to levy duties and taxes, and to regulate transportation. Nor is it to the interest of the people that a Constitutional amendment should be adopted vesting in the United States the proposed power of regulation. The fatal facility of compromise as shown in the history of the slavery question and the silver issue, and exhibited in every tariff act, and the lack of appreciation of the demands of legitimate business as evidenced by the failure of Congress to do away with the antiquated sub-treasury system and to authorize an elastic currency, demonstrate the unwisdom of vesting in Congress a power which, if exercised, may injuriously affect the business interests of the country.

So far as concerns Congressional legislation under the Constitution as it now is, it would seem that the Supreme Court has put the question at rest, for it has decided[3] that "the relief of the citizens of each State from the burden of monopoly and the evils resulting from the restraint of trade among such citizens were left with the States to deal with;" and that an organization to manufacture and sell is a subject matter of State regulation, for the reason that, while it may bring the operations of commerce into play, it affects

[1] McCulloch *v.* Maryland, 4 Wheat., 316.

[2] U. S. *v.* De Witt, 9 Wall., 41; McGuire *v.* The Commonwealth, 3 *id.*, 387; Patterson *v.* Kentucky, 97 U. S., 501.

[3] U. S. *v.* E. C. Knight Company, 156 U. S., 1, 11.

commerce only incidentally and indirectly. That judgment is unreversed and unshaken, and it is to-day the law of the land.

In the past, the country has had to overcome, under conditions of inadequate transportation facilities, the disintegrating tendencies of the expansion of territory and the growth of population, but as the results of the triumph of the nation in the suppression of the Rebellion, and the development of means of transportation and communication, our perils are now those of governmental consolidation and not those of dissolution. The silver legislation, threatening a degradation of the standard of value; the income taxing law of 1894, unnecessarily vexatious and inquisitorial in its provisions and, by reason of its exemption of incomes less than $4,000 in amount, unjust and unequal in its intended operation; and the laws imposing taxes upon inheritances, increasing progressively in proportion to the amount of the distributive share and teaching the many to expect that the necessary expenditures of government will be borne by taxation to be levied on the few, are illustrations of the perils which may threaten the prosperity of the country. Any legislation which conflicts with the American doctrine that all men are equal before the law, and that equality of rights implies equality of obligations, and that subjects rights of property and freedom of contract to administrative control, is dangerous in a republic governed by universal suffrage.

Every State should encourage the organization under proper conditions of manufacturing and trading corporations, and it should permit them to do any business that an individual may lawfully do. While a State should not undertake to guarantee to the public "in all particulars of responsibility and management" the corporations organized under its authority, it should by conditions annexed to the grant of the charter protect intending and actual shareholders and creditors of the corporation, so far as can be done. It should prohibit and punish fraud in organization or administration. It should afford access to public records showing how the capital has been or is to be paid, and if paid in property, so describing and identifying that property that its value can be tested. It should require the publication at stated periods of balance sheets stating the liabilities under the headings of "shares," "bonds," and "other indebtedness," and the assets under the headings of "real estate and machinery at cost" less stated amounts charged off for depreciation, "cash," "debts collect-

ible," and other "assets," and it should compel the publication at stated periods of an income account, setting forth the total amounts of gross earnings, of operating expenses, interest charges, dividends, and undivided profits. It should also protect minority shareholders by defining the powers of officers and directors, and by requiring due notification of shareholders' meetings.[1] The duties imposed upon the corporations and their officers and the requirements as to reports should be fixed by law, and should not be subjected to the discretion of public officers. If so subjected, there will be a possibility of favoritism on the one hand, or of political intimidation on the other.

The officers and directors of a corporation are trustees for its creditors and shareholders. It is the duty of such trustees, and the interest of their *cestui que trusts*, that there should be, on the part of the trustees, absolute good faith, and as much frankness as is consistent with the protection of the rights of shareholders. No other policy will commend the securities of a corporation to the favorable consideration of investors. Nevertheless, it is certain that no amount of legally enforced publicity will avail to prevent unwise investments and consequent loss. Those who may properly encounter the risks of investment in industrial securities will not do so before they shall have obtained for themselves information as to honesty of organization and adequacy of earning capacity. Those in whom the haste to become rich, and the disinclination to wait for the slow but sure results of industry and frugality have caused a fever of speculation, will take the chances and buy for a rise in the market without regard to the condition of the corporation, real or reported.

Neither the government, nor the public, nor even the purchasers of Trust products provide the capital of the Trusts, but that capital is contributed by their bondholders and shareholders. In so doing, they are not making investments which are of certain return, either in principal or income. As they take the risk of loss, they are entitled to security in their business, to protection in the use of their properties, and to a return proportioned to the risk they have taken and exceeding the current market rate of interest upon securities of a higher grade.

[1] 1903, Report of the Massachusetts Committee on Corporation Laws, by H. M. Knowlton, C. G. Washburn, and Frederic J. Stimson.

While the corporation is a legal entity, distinct from the bondholders and shareholders who contribute its capital,[1] nevertheless the fact remains that the bondholders and shareholders are the persons, or the successors of the persons, whose contributions in money or in property, real or personal, constitute the capital of the corporation, and it is they, or their successors in title, who are benefited by the prosperity of the corporation or injured by its adversity. In the days of the "greenback" agitation, the "bloated bondholder" was the object of fierce denunciation, but when the facts were investigated it was found that the "bloated bondholders" were the saving funds, with whom were deposited the accumulated earnings of labor, the insurance companies, to whom every provident man looked for the future protection of his dependent wife and children from want in case of his death, and the banks, with whom all business men, great and small, deposited the money which they needed for daily personal and business use. Again, when the banks were assailed as heartless money lenders and oppressors, it was seen that the profits of banking accrued to the men, women, and children, who were the shareholders. Again, when Mr. Bryan, in 1896 and in 1900, denounced the holders of "fixed investments" and "the idle owners of idle capital," intelligent people knew that those whose interests he threatened with destruction were the depositors in saving funds, the shareholders in banks, and the holders of policies of life insurance. It will likewise be found to-day that those whose interests will be injured by unwise legislative restraints upon trade and industry will be the workingmen to whom the Trusts offer employment, and the hundreds of thousands of individuals who are, directly or indirectly, the owners of the securities of the Trusts. The leaders of public opinion will do well to remember that, as Mr. Lecky has said,[2] it is an inexorable condition that all "legislation which seriously diminishes profits, increases risks or even unduly multiplies humiliating restrictions, will drive capital away and ultimately contract the field of employment."

[1] Regina *v.* Arnoud, 9 Q. B. 806, 58 E. C. L.; Van Allen *v.* The Assessors, 3 Wall., 573.

[2] *Democracy and Liberty*, Vol. II, page 463.

THE INCLUSION AND OCCLUSION OF SOLVENT IN CRYSTALS.

An Insidious Source of Error in Quantitative Chemical Investigation.

BY THEODORE WILLIAM RICHARDS.

(*Read April 4, 1903.*)

Perhaps the most frequent and the most insidious cause of error in quantitative chemical research is the unsuspected presence of water. The disturbing effect of this impurity is frequent, because water is one of the most plentiful of substances; and insidious, because there is usually no easy quantitative or qualitative test for small quantities of it.

The object of this paper is to recount several experiments indicating the prevalence and magnitude of inaccuracy from this cause, to show how many published results have been vitiated by it, to emphasize the theoretical aspect of the phenomenon, and especially to point out the methods of reducing the inaccuracy to a minimum.

In a number of isolated cases it has been shown by various chemists that substances crystallizing from a solution enclose within their crystals small quantities of the mother-liquor. It is very well known, for example, that crystals of common salt explode or decrepitate upon being heated, because of the vaporization of the enclosed water. Thus when common salt is weighed some water is weighed with it. This water is not combined as water of crystallization, of which common salt has none; it is entirely accidental. Following the nomenclature of the mineralogists, a liquid imprisoned in this way is best called "Included solvent." The mother-liquor is thus imprisoned, in addition to combined water, also in salts which contain this latter as an essential part of their crystal structure; in these cases it is even more difficult to detect and more generally overlooked, because of the simultaneous presence of the combined water.

Although these facts have been thus occasionally pointed out, the frequency of the occurrence of this cause of error has not often been realized by quantitative analysts. It is no careless exaggeration to state that in all my chemical experience I have never yet obtained crystals from any kind of solution entirely free from accidentally included mother-liquor; and, moreover, I have never found reason to believe that anyone else ever has. Whether the

solvent is water, an organic liquid, or a fused salt at high temperature, and whether the crystallization is quick or slow, in small or large crystals, the effect is always traceable, although of course in varying degrees. The amount of the enclosure varies from perhaps 0.01 per cent. to 0.5 per cent. of the total weight of the crystals.[1]

As a general rule, the clearer the crystal, the less the included mother-liquor; but appearance is not a wholly safe guide, since sometimes the refractive index of the mother-liquor is not far from that of the crystal. In this case the included impurity is invisible. Moreover, the inclusion may, and undoubtedly does, often occur in cells so small as to be beyond the reach of the best microscope.

It is not contended that the production of a perfectly pure crystal from a solution is impossible, but only that no evidence has been obtained proving that this end has ever artificially been reached, while much contrary evidence is available.

In looking over the records of the determinations of atomic weights, it is surprising to see how many experimenters in even this most exact field of quantitative analysis have either entirely overlooked the danger, or have taken inadequate means to overcome it. This is especially true when the salts to be weighed contain combined water of crystallization; indeed it is almost safe to rule out utterly all such results, without further consideration. Among other more or less vitiated cases, where salts supposedly anhydrous have been weighed, may be mentioned especially a number of the analyses of typical salts of osmium, iridium, platinum, and palladium. Often a painstaking but unthinking chemist has spent months in eliminating the *hundredth* of a per cent. of some foreign metal and finally ignored the *tenth* of a per cent. of water in his preparation. It is not, however, the purpose of this paper so much to seek the errors in individual instances of past work, as to point out the ways in which these errors may be avoided in the future.

How then is this included solvent to be eliminated without decomposing the substance which we desire to weigh?

It is usually considered as a sufficient precaution to powder the material finely and expose it to the air for a short time, in order to allow the undesirable water to evaporate. This crude proceeding involves a double uncertainty; in the first place, the unwar-

[1] For examples of carefully obtained evidence, see Richards, *Proc. Amer. Acad. Arts and Sciences*, 23, p. 177 (1887); 26, p. 267 (1891); 28, p. 11 (1893); 29, p. 60 (1893); 33, p. 299 (1898); 35, p. 139 (1899); 37, p. 434 (1902); 38, p. 411 (1902).

ranted assumption is made that every hidden cell containing the mother-liquor has been split open by the pestle, and in the next place the equally unwarranted assumption is made that all the mother-liquor thus exposed evaporates into the uncertain mixture constituting the atmosphere of the laboratory.

The former of these assumptions will be considered first. Is it possible to open all the cells enclosing mother-liquor by means of any finite amount of powdering?

This question cannot be answered *a priori*; accurate experiments are needed to decide it, and no published work known to me seems to furnish the needed data. Accordingly a series of experiments was planned which involved the progressive powdering of a typical substance. In order to separate the powders of different degrees of fineness four pieces of brass netting were used, having openings about 0.5, 0.3, 0.23, and 0.16 mm. in diameter respectively. This netting was cleaned with acid and ammonia, and showed a brilliantly clean surface in the microscope.[1]

The test substance chosen was baric chloride, because careful experiments on the atomic weight of barium had shown that it may be analyzed with ease and accuracy. A pure finely-crystallized specimen of the salt was slowly and carefully powdered and sifted through the successive sieves. That which went through the finest sieve was still more finely powdered, until the average diameter of the particles as estimated in the microscope was perhaps one-twentieth of a millimeter, some being coarser and some finer. Each specimen was thoroughly air-dried.

Thus were obtained four examples of baric chloride containing crystal-water, of four different degrees of fineness, the coarsest particles averaging about a thousand times the bulk of the finest. Upon analysis by heating to constant weight at 400° these samples yielded respectively 14.780, 14.771, 14.763, and 14.760 per cent. of water.

The data, reduced to the vacuum standard, were as follows. The experiments were made in 1893:

No.	*Average diameter of particles.*	*Weight of salt.*	*Loss on heating.*	*Per cent. of water found.*
1	0.45 mm.	4.15929	0.61475	14.780
2	0.27 mm.	3.65127	0.53933	14.771
3	0.20 mm.	4.54136	0.67047	14.763
4	0.05 mm.	10.13720	1.49620	14.760

[1] The material sifted through this netting was tested for copper, with satisfactorily negative results.

The results thus show a steady decrease in the amount of water as the powder becomes finer; hence each successive powdering must have opened new cells.

When the figures are plotted a somewhat irregular curve is obtained, the study of which seems to show that further powdering would have but little effect upon the last-named amount of water held by the crystals. As a matter of fact, among many scores of determinations of the quantity I have never found in a pure specimen of baric chloride less water than this. Is this limit then, observed in the very fine state of division, the true amount of water in the salt? This question is easily answered in the negative, for from the universally accepted atomic weights of barium, chlorine, oxygen and hydrogen it is easy to calculate that the theoretical amount of water is 14.744 per cent., an amount less by one part in a thousand than the lowest limit recorded above.

Similar results were obtained from cupric sulphate, and it seems probable that any other salt would behave in the same way. Thus it appears that although powdering and drying will diminish the excess of solvent, it will not wholly remedy the error. It is probable that anything short of molecular division would fail to open the minutest enclosing cells, although the larger cells are broken up with comparative ease.

The irregular shape of the curve drawn from the data given suggests that there is another cause of error superposed upon the effect just studied—an influence which grows in magnitude as the fineness of the powder is increased. A moment's reflection serves to show what this new cause of error must be.

It is well known that water adheres to or wets almost anything, except a few fats and oils; and even these absorb or dissolve water to some extent. In consequence of this tendency to adhere, water is condensed or *adsorbed* in an invisible film, from the always slightly moist atmosphere, upon the exposed surface of nearly all substances. This adhering film increases the weight of these substances.

The extent of the adsorption varies with the nature of the substance and in many cases is easily appreciable. With a given substance it is of course dependent upon the pressure of the aqueous vapor and the temperature, as well as upon the extent of surface.

Since the adsorption increases with the surface it is evident that fine pulverization, while tending to diminish the inclusion, will

tend to increase this new cause of error by increasing the field of its action.

Thus the irregularity of curve shown by the results with baric chloride is easily explained, as well as the abiding presence of an excess of water. In the effort to escape the Scylla of inclusion the chemist has run foul of the Charybdis of adsorption.

Adsorption of aqueous vapor can be eliminated by greatly raising the temperature or by greatly reducing the tension of the surrounding aqueous vapor. These means may be used either with anhydrous salts or with the sundry chemical vessels used for containing substances while weighing; but unfortunately either of these changes drives out also the crystal-water contained in a hydrated salt.

For these reasons it seems to me impossible to determine with the exactness demanded in the most accurate work the true weight of any salt containing water of crystallization.

In the case of *anhydrous* salts, which may be heated and placed in a perfectly dry atmosphere without decomposition, it is easy to eliminate adsorbed moisture, as already stated. It is not by any means so easy, however, to drive off the included solvent imprisoned in hidden cells. Some means must be used which disintegrates the walls of these cells; and the means adopted depends upon the nature of the substance being studied.

Either mechanical, thermal or chemical influences may be used to effect the disintegration. The mechanical means, pulverization, need not be further discussed. The application of heat first tends to vaporize the imprisoned solvent, if it is volatile, causing great pressure in the small space. This pressure often causes the enclosing cell to explode, and thus the solvent is set free. It is not by any means certain, however, that all the cells are thus able to discharge their contents, especially in tenacious substances; and in many cases hours of intense heating are necessary to drive off every trace of water, as with silica and iron rust. In the case of metals precipitated as such from aqueous solutions, temperatures not far from the melting-points must be used for drying, in order that their condition may be soft enough to yield to the internal pressure of the enclosed solvent. This precaution has usually been overlooked by physicists determining electro-chemical equivalents, although Lord Rayleigh pointed it out in the special case of silver twenty years ago.

A much safer plan, where it is practicable, is to *fuse* the cystalline precipitate. With the freedom of motion given by the liquid state volatile impurities usually soon escape, leaving the fused mass free from them. It is true that there is often danger that a portion of the substance itself will evaporate, or at least that it will attack the containing vessel; minute precautions must be used to avoid these causes of error. In extreme exigency the electrolysis of the fused mass, a plan suggested by Richard Lorenz, may be used as a means of destroying the last traces of water; but in most cases these may be swept out by the vapors from easily decomposed ammonium salts, just as bubbling air sweeps out carbonic acid from its solution.

A yet further and better thermal means of preparing a substance free from water is to vaporize and condense or sublime it in a perfectly dry atmosphere. Here crystals form under conditions excluding water, and the danger is wholly overcome. Unfortunately other impurities are usually introduced from the walls of the vessel used for the sublimation; but frequently these may be found by analysis much more directly and precisely than the water could be.

A chemical method of disintegrating the structure of a substance crystallized from a solution has been alluded to above. This method, although not always available, may sometimes serve when the other methods are inapplicable, and is often of great use in preparing chemically pure substances. This procedure, like the others, has been used in individual cases for years; but it does not seem to have been emphasized as a general method.

In brief the chemical method is as follows: The substance is crystallized from the solution, not directly in its desired form, but rather in chemical combination with a large quantity of some other substance which may be volatilized by suitable subsequent treatment. The clear, dry crystals are then subjected to this decomposing treatment, and the volatile constituent is expelled. The substance sought is thus left in the form of a porous mass, a skeleton of the former crystal, in which every cell enclosing mother-liquor has been opened by the chemical disintegration of its walls. From such a skeleton soluble impurities may often be washed out by lixiviation, and volatile ones escape at once.

For example, it is easier thoroughly to dry sodic carbonate when this salt is crystallized with its maximum amount of crystal-water,

than it is when the salt is crystallized immediately in the form devoid of crystal-water. Again, it is far easier to obtain pure iron by the reduction of the oxide in hydrogen than it is by electrolytic precipitation direct from a solution.

Yet another chemical method might sometimes be helpful, although inherently of a somewhat restricted usefulness. In a careful study of the behavior of gases included in oxides,[1] it was found that in these compounds oxygen could work its way out from a cell in which it exists under pressure, while nitrogen could not. It is possible that this fact is typical of a general principle; that any substance may escape from pressure when this substance forms one of the easily dissociated components of the containing walls, by a process of alternate dissociation and recombination of the materials constituting these walls. Thus certain hydrated salts, heated to a temperature of perhaps 120° in superheated steam at atmospheric pressure, might in time part with their enclosed water without losing their water of crystallization. This inference will be further tested in the near future.

In this connection, one other point must be strongly emphasized, because of its important bearing both upon chemical purification and upon dynamic geology. The microscopic cells in a crystal contain not only the solvent, but also all the other substances in the solution. They are miniature samples of the solution, not perhaps in strict quantitative measure, because of varying adsorption, but at least qualitatively.

Hence, if a chemically pure substance is desired, great pains must be taken to keep away from the solution anything which cannot be expelled or extracted from the disintegrated crystal, after the enclosures have been opened. For example, pure iron must be obtained by the reduction of oxide or hydroxide obtained from the nitrate, not from the sulphate. If the latter salt were used, the iron would probably contain sulphur. This practice of continually avoiding impurities obviates also the possible danger from "solid solution," as van't Hoff pertinently terms the *homogeneous* distribution of foreign matter in a solid. Solid solution, or *occlusion*, may be said to be the limiting case of *inclusion*. In this limiting case the enclosing cells are so small as to contain only single molecules. The distinction between occlusion and inclusion in solids is theoretically interesting, corresponding perhaps to the difference

[1] Richards, *Am. Chem. Jour.*, 20, p. 701 (1898).

between true solution and colloidal solution in liquids; but for present practical purposes this difference need not be further emphasized.

All these considerations have been carefully heeded in the recent determinations of atomic weights made in this laboratory.

Since the fundamental properties of material have probably not changed since the archæan times of mineral growth, natural crystals must have been subject to the same effects as those grown to-day, and all except those formed by sublimation must contain traces of the solutions from which they once separated. In some cases, of course, the very slow formation might reduce the inclusion to a very small amount. Those minerals coming from aqueous solutions would be supposed to contain accidentally enclosed water (often erroneously confounded with the true water of constitution), while those separating under fused or metamorphic conditions would contain non-volatile impurities taken from their immediate surroundings. Of these impurities the non-volatile ones must certainly remain; and many of the volatile ones may also, if closely enough imprisoned. As a matter of fact, we are very familiar with the traces of impurity in natural crystals, even the clearest of diamonds leaving some ash on combustion.

While the selective effects of adsorption and solid solution and the results of subsequent pressure must complicate the interpretation of these facts, and forbid their immediate quantitative utilization, it seems to me nevertheless that these enclosed traces of impurity might be used more often than they are used in geological reasoning, in order to discover the media from which crystals have separated, and hence the mechanism of their formation. Thus a phenomenon very troublesome to the chemist might become very useful to the geophysicist.

The contents of this paper may be summarized briefly as follows:

(*a*) Experiments are recorded and quoted showing that many, if not all, crystals separated from solutions contain included mother-liquor.

(*b*) The experiments show also that before the mother-liquor can be eliminated by pulverization the adsorption of water from a moist atmosphere begins to augment the weight of the substance.

(*c*) It is pointed out that this adsorption cannot be wholly overcome in the case of hydrated salts without a loss of water of crystallization also. Hence hydrated salts cannot be accurately weighed according to any usual procedure.

(*d*) In the case of anhydrous salts the elimination of adsorption is easy, but in order to remove included solvent the cell walls enclosing it must be disintegrated.

(*e*) Mechanical, thermal and chemical methods of such disintegration are classified and applied to the preparation of pure materials.

(*f*) It is pointed out that other impurities besides the solvent will usually be enclosed in the cells, and that these other impurities must never be forgotten in subsequent processes of purification.

(*g*) Finally, it is suggested that these enclosed impurities might be used more frequently than they are as a clue to the manner of growth of natural minerals, and hence to the mechanism of geophysical processes.

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A RÉSUMÉ OF THE COMPOSITION AND OCCURRENCE OF PETROLEUM.

BY CHARLES F. MABERY.

(*Read April 3, 1903.*)

I have said and written so much about petroleum during the last fifteen years, it may seem that I have reached the limit of interest and about exhausted the subject. Twenty years ago when I first went to Cleveland I began the study of petroleum, and have since devoted a considerable portion of my time to the examination of the constituents of petroleum from many different fields. But instead of exhausting the subject it is evident that only a beginning has been made, and the foundation for what is probably the most difficult and intricate parts of this interesting field of research.

The series of hydrocarbons which form the portions of petroleum distilling below 350° *in vacuo*, corresponding to 475° atmospheric pressure, are now well understood, and the members of the various

[1] The subject matter of this paper is based on the results of work carried on in the chemical laboratory of Case School of Applied Science, with aid of grants by the American Academy of Arts and Sciences from the C. M. Warren fund for chemical research.

series have been identified with respect to their molecular weights. But concerning the structure of these hydrocarbons, except those of the series C_nH_{2n+2} and the lower methylenes nothing whatever is known. It is reasonable to assume that the members of the series C_nH_{2n+2}, or the so-called paraffine hydrocarbons, have the open-chain structure which characterizes the lower members of this series. In earlier literature on petroleum it was generally assumed that the ethylene hydrocarbons, series C_nH_{2n}, formed a considerable proportion of the constituents, and even after the discovery of the series C_nH_{2n}, the naphthenes, according to the earlier nomenclature of Markownikow, many writers still insisted on the presence of the ethylene hydrocarbons. It is now safe to assert that these bodies are present in any petroleum at most in very small amounts. We have found them apparently in Canadian petroleum, but in very small quantities.

The series C_nH_{2n}, which has been identified in petroleum from many sources, is now well known as the methylene series. In a paper published last year on the composition of Pennsylvania petroleum, I purposely abstained from naming the hydrocarbons with high boiling points of this series which we had separated and identified, for although it seemed probable that these bodies were methylenes, I preferred not to suggest names for the several members until more is known concerning their structure. The names suggested by Dr. Bogert in his summary of the results described in that paper for the *Journal* of the American Chemical Society, seems to refer those hydrocarbons to the ethylene series; but any nomenclature for these bodies must await sanction by proof of structure when some courageous investigator shall force his way into this difficult field.

Another feature of the petroleum problem is the form of the hydrocarbons which form the highest boiling portions—the so-called asphaltic hydrocarbons. The main body of these high boiling oils are no doubt composed of series poorer in hydrogen than the methylenes, the series C_nH_{2n-2}, C_nH_{2n-4}, etc. The hydrocarbons of these series already appear in the higher boiling portions of Pennsylvania, Ohio, Canadian, etc., petroleum, as we have shown in part, although much of this data has not yet been published.

It does not at present seem clear how this problem shall be attacked. By exclusion of air and depression of boiling points the petroleum hydrocarbons can be distilled indefinitely as high as

350°. Between 300° and 400° cracking begins, and it cannot be avoided by straight distillation. The heavy hydrocarbons seem to become so inert, by reason of their high molecular weights, they cannot retain their atomic composition at their boiling points; they simply fall to pieces through the influence of mass. In distillation from the crude oil evidently another influence comes into operation—the effects of the oxygen, nitrogen and sulphur constituents. Since fractional distillation is the only means at present known for the separation of the homologous members of these series, the problem of their isolation becomes a difficult one.

Nevertheless I regard this field as offering great attractions, provided, as I mentioned some time ago, suitable facilities are provided for carrying on the work. A grant of $5000 annually from the Carnegie University could be made to yield results commensurate with the expenditure, for there is no more promising field for research of such magnitude awaiting a vigorous hand. As for myself, I shall be content with what I have been able to accomplish with the aid of the C. M. Warren fund and the facilities of the Case School laboratory in defining the series and principal members in petroleum from different fields that has come under my observation.

In presenting a general summary of present knowledge concerning the composition of petroleum, it may be of interest to refer to what was known on this subject twenty years ago when I began the work. At that time the only petroleum on the market in America was obtained from the Pennsylvania fields and the territory in Canada. The composition of Russian petroleum was then under investigation by Markownikow. As a result of their elaborate investigation on American petroleum Pelouze and Cahours had assigned the formula C_nH_{2n+2} as representing the principal series of hydrocarbons. But the high specific gravity of their distillates could not have been given by hydrocarbons separated from Pennsylvania petroleum, since these bodies give much lower values. Since the source of their products was not mentioned, it must be assumed that they came from the heavier Canadian oil, although the hydrocarbons in this oil have not the composition of the series C_nH_{2n+2} which Pelouze and Cahours deduced from their analyses, but, as we have found by results not yet published, the composition of the series C_nH_{2n}. Pentane, hexane, heptane and octane had been identified by Schorlemmer, and the classic work of C. M.

Warren had shown the existence in Pennsylvania petroleum of the two series of isomeric hydrocarbons from pentane to octane. The large deposits of petroleum in northern Ohio and Indiana, Texas, Colorado, Wyoming and Kansas had not then been discovered.

In 1885, soon after the first well was drilled that yielded oil from the Trenton limestone, two oil inspectors brought me a five-gallon can of Trenton limestone oil and remained while I examined it for them. This was my first acquaintance with the sulphur petroleums. I recognized at once the large percentage of sulphur and soon afterward began a study of the sulphur compounds. I am not now fully satisfied as to the nature of those sulphur compounds. Not long afterward I also procured the Canadian sulphur oil, and carried along together the study of these products, the one from Trenton limestone and the other from the Canadian Corniferous limestone. The composition of Ohio oil has only recently been determined, with respect to the principal series of hydrocarbons, by a research completed during the present month, seven years after it was begun. At first I had no preconceived ideas as to the series of hydrocarbons which compose these crude oils, except what knowledge I had gathered from the work of my predecessors; but after the work had progressed far enough to see that the crude oils from the different fields were essentially different in certain constituents, especially in sulphur, I was inclined to look on the Trenton and Corniferous limestone crude oils as a special species, the sulphur petroleums, and to agree with Peckham in his specific classification of the different petroleums as varieties of bitumens. But I soon became convinced that no such sharp distinctions based on composition could be drawn. Now after these years of arduous labor I have reached the conclusion that petroleum from whatever source is one and the same substance, capable of a simple definition—a mixture in variable proportions of a few series of hydrocarbons, the product of any particular field differing from that of any other only in the proportion of these series and the members of the series. I arrived at this conclusion only one year ago, when it was found that the higher distillates from Pennsylvania petroleum contain the series C_nH_{2n-2}, which until then I had supposed was only to be found in the heavier California and Texas oils, or the so-called asphaltic oils. Results obtained within the last two months show that Ohio petroleum has a similar composition.

In support of this definition I would suggest that, so far as known,

all petroleum contains nitrogen and sulphur, although the proportion of nitrogen in Pennsylvania and Ohio crude oils is much smaller than that in California oil, and that the percentage of sulphur is much smaller in the Pennsylvania sandstone oils—only a trace as compared with the larger amounts in Trenton limestone, Corniferous limestone, in California and Texas oils. With this definition the distinction drawn, at least in commercial circles, between paraffine and asphaltic oils disappears, for Pennsylvania crude oil contains the asphaltic hydrocarbons, although I cannot assert that California oil contains paraffine. I have crystalline hydrocarbons separated from California oil, but their identity is not yet fully established. The refiner is more definite in his classification; he knows from experience that the best yield of gasoline is from Pennsylvania oil, and none from California oil. He is fully aware that it is useless to expect to obtain a respectable yield of burning oil from California or Texas petroleum, and that he cannot hope to obtain paraffine from those heavy oils. But his very heavy lubricating oils and heavy pitches and asphalts he knows can come only from the heavier petroleums.

With reference to a nomenclature of the petroleum series and hydrocarbons, no system can safely be adopted until the structure of these bodies is better understood. The aromatic hydrocarbons benzol and its homologues are present in all petroleum so far as examined, but in widely variable proportions. Pennsylvania crude oil contains the lower members in small amounts, but not the higher homologues. It is true that anthracene and its congeners have been described as separated from petroleum residues, but it is probable that such bodies are not present in the original oil; they are doubtless formed by decomposition during distillation. California petroleum contains much larger proportions of the aromatic hydrocarbons, especially of the xylols and others with higher boiling points. In one of our distillates from California crude oil so much naphthaline was present that the distillate became solid on slight cooling. This distillate came over at about 215°. The only other instance in which naphthaline has been found in petroleum was its separation by Warren and Storer from Rangoon petroleum.

The terminology of the series C_nH_{2n+2} has been well defined, and the names adopted by Kraft for the members with high boiling points, liquids and solids, which he separated from shale distillates are applicable to the corresponding bodies in Pennsylvania crude

oil. It is interesting to note that Pennsylvania petroleum alone, unless we include the analogous Berea Grit and other similar sandstone oils of southern Ohio and Virginia, contains the unbroken series up to and including the solid paraffine constituents. Although the Ohio Trenton limestone oil and the Canadian Corniferous oil contain paraffine, the former in large proportions, the liquid members of series C_nH_{2n+2} stops with $C_{11}H_{22}$ in both Canadian and Ohio oil. The liquid hydrocarbons from there on, so far as examined, are members of series poorer in hydrogen.

The series C_nH_{2n} has been variously named. When first discovered in petroleum, and the hydrocarbons found to be identical with the hydrogen addition products of benzol and its homologues, the hydrocarbons from petroleum were described as hexahydro-bodies. On the discovery of a long series of these hydrocarbons in Russian oil, Markownikow suggested the name naphthenes. But when later the origin and nature of the methylenes were better understood and cyclic hydrocarbons found in petroleum identical with the synthetic products, the name methylene was adopted for the lower petroleum hydrocarbons. These closed-chain hydrocarbons differ in their deportment toward reagents from those with an open-chain, C_nH_{2n+2}. While it is to be assumed that the series C_nH_{2n} is represented in its higher members by the methylenes, some extension of the nomenclature is necessary to include those bodies. There can evidently be but one ring with these proportions of carbon and hydrogen. For instance, the hydrocarbon $C_{12}H_{24}$ must be regarded as a long chain with the ends connected, dodecamethylene, or a lower ring with several side chains.

When the series C_nH_{2n-2} is reached it becomes necessary to assume a union of two rings attached by one carbon atom in each ring. In the series C_nH_{2n-4} the union would be between two carbon atoms in each ring and the members should include, for instance, octohydronaphthaline which would represent the hydrocarbon $C_{10}H_{16}$. In the line of this suggestion, following the analogy of naphthaline, one side chain should be capable of oxidation giving a derivative of phthalic acid. But the methylene hydrocarbons seem to possess a different order of stability toward the action of reagents, and we have observed this peculiarity in bodies separated from petroleum which appear to be derivatives of the methylenes. For instance, the nitrogen compounds separated from California crude oil cannot be oxidized into closely allied products, the

oxidation always proceeding to the formation of ultimate products, nitrogen and CO_2, and we have found it impossible to check it.

The same is true of the sulphur compounds, which also appear to be methylene derivatives. These bodies oxidize with the greatest ease to sulphuric acid, and it is difficult to control the oxidation. We have done this, however, and have obtained well-defined sulphones. In general terms, the addition of hydrogen to benzol and its homologues weakens the resistive action toward reagents. This difference in stability between the series C_nH_{2n+2} and the series poorer in hydrogen appears in commercial use of the heavier products. We have recently compared the flashing point and fire test to heavy distillates from Pennsylvania crude oil and crude oils from California, Texas, etc., and it appears that the products from Pennsylvania oil have higher flashing points and fire tests than those from other fields. We have an excellent opportunity to ascertain the general application of this observation, for we have at hand samples in gallon lots of the principal lubricators made from Pennsylvania and Ohio oils on the market, and also samples of crude oils from the various fields; for example, two barrels of crude oil from Baku in the Russian field.

Products are now being prepared from the crude oils to compare with Pennsylvania lubricating oils. The inferior stability of petroleum which the series C_nH_{2n} or series poorer in hydrogen predominates has appeared in all our work on the various crude oils. For instance, the admission of air into hot Pennsylvania distillates never causes an explosion; but explosions are sure to follow the contact of air with hot distillates from other fields where the principal series is lower than the series C_nH_{2n+2}.

In combustion it is easy to see the difference in stability, in the readier separation of carbon. Then in analysis of a series, say from $C_{12}H_{24}$ to $C_{22}H_{44}$, in the lower members no carbon separates in the boat, but it gradually appears with increasing molecular weight, in larger and larger amounts.

The greater stability of the hydrocarbons C_nH_{2n+2} doubtless explains the superior quality of burning oils prepared from Pennsylvania petroleum, together with the fact of a larger proportion of hydrogen. The series poorer in hydrogen more readily separates carbon as soot and is more difficult to burn. A mixture of the two series C_nH_{2n+2} and C_nH_{2n} forms a good burning oil and probably accounts for the excellent quality of Russian burning oil.

As I shall presently explain, Ohio crude oil contains a much smaller proportion of the series C_nH_{2n+2}, and it cannot be expected to yield burning oil of as good quality as Pennsylvania crude oil. Canadian burning oil should be still poorer in quality, which is easily seen by the consumer who will pay a high duty on United States oil rather than use his own product.

Pennsylvania Petroleum.

As mentioned above, Pennsylvania crude oil contains minute amounts of sulphur and nitrogen compounds, and a small proportion of benzol derivatives; but the great bulk of the oil is composed of the series C_nH_{2n+2}, beginning with the butanes and ending with solid hydrocarbons of such high molecular weights that they cannot be determined by any method now known. We have reached the hydrocarbon $C_{28}H_{58}$, and it is the last one of the series whose molecular weight could be determined. It is quite probable that there are as many as eight or even more of the hydrocarbons with greater molecular weight.

It has been an open question with practical oil men, and perhaps is still with some, as to whether solid paraffine is contained in crude petroleum or whether it is formed in the process of distillation. In the ordinary process of refining crude oil, a very considerable proportion of the hydrocarbons is lost in the last stages of the destructive distillation which ends with a large mass of coke. On comparing the thin liquid crude oil with products obtained from it in refining, it would be natural for the superficial observer to reason, from the appearance of coke at the end of the distillation and other heavy products, that solid paraffine should be formed in a similar way by decomposition of the light liquid crude oil.

But careful consideration of the nature and origin of petroleum precludes the possibility of its formation by distillation. It is true that paraffine was first obtained by Reichenbach by the distillation of vegetable and animal organic matter, and there is no question that it has been formed in a similar manner by natural processes. But petroleum must be regarded as a final product of decomposition, and while the series may be changed from one to another to a limited extent, decomposition of the constituents leads to the formation of simpler products until finally carbon is reached. Therefore, instead of paraffine as a result of decomposition of other

hydrocarbons, paraffine itself is decomposed into hydrocarbons of lower molecular weight. But while this view is well supported by the facts observed relating to the nature of paraffine, we have not been satisfied with less than actual proof by experiment of its presence in crude oil, and several lines of work have been carried on in this direction.

Last year we placed several liters of crude petroleum in a large flue of the laboratory, with strong draught, and allowed it to evaporate during several weeks. Much the larger portion of the original oil had evaporated, and the residue was so very thick it would scarcely flow. By careful extraction of the oil with ether and alcohol we obtained a small amount of solid paraffine, as shown by its melting-point and resemblance to ordinary solid paraffine hydrocarbons.

In another line of work, the results of which have not been published, we procured ten gallons of a semi-solid mass of hydrocarbons from a refining company at Coreopolis, Pa., that had been collected from the sucker rods in pumping oil and had never been distilled; this oil is very heavy, light yellow in color and is used for the preparation of commercial cosmolines and vaselines. By cooling some of this product and crystallization we were able to separate from it a mixture of hydrocarbons closely resembling paraffine. A considerable portion of this pasty mass was subjected to fractional distillation, and a series of hydrocarbons separated with the composition of the series C_nH_{2n+2}. The oils separated by cooling and pressure gave results on analysis corresponding to series poorer in hydrogen.

We next took up the composition of the mixtures that form the vaselines and cosmolines. The refiner makes a sharp distinction between crystallizable and uncrystallizable paraffine. But there seems to be but one form of solid paraffine hydrocarbons. Vaseline is simply a very heavy oil saturated with paraffine, and containing an excess of solid paraffine in the form of an emulsion. The oil is composed of the heavy oils of the series C_nH_{2n} and C_nH_{2n+2}, and the solid bodies members of the series C_nH_{2n+2}. The so-called scale paraffine of the refiner is solid paraffine containing sufficient of the heavy oils to prevent it from assuming a well-defined crystalline condition.

The appearance of the series C_nH_{2n} and the series C_nH_{2n-2} in Pennsylvania petroleum distillates, as shown in a paper published

last year, indicates that the so-called asphaltic hydrocarbons form a part of this petroleum with very high boiling points. This places Pennsylvania petroleum in the same category with the heavier petroleum from such fields as California and Texas, the chief differences being the predominating series C_nH_{2n+2} in Pennsylvania oil and the series poorer in hydrogen in the heavier products. As explained above, the large proportion of the paraffine hydrocarbons in the heavy portions of Pennsylvania oil apparently render the lubricating distillates more stable. Just what effect it has on the lubricating qualities, so far as I know, has not been completely determined. Some experiments on the very heavy lubricants from Beaumont oil have demonstrated very superior lubricating qualities.

Ohio Trenton Limestone Petroleum.

Since the first discovery of this petroleum, there has been great uncertainty concerning its composition. In the preparation of commercial products, the refiner discovered essential differences between it and Pennsylvania oil which were fully understood with reference to its refining qualities. The first serious obstacle was the large amount of sulphur compounds that must be removed for the production of acceptable burning oil. Innumerable patents were issued for processes which included distillation over quartz, precipitation with mercuric chloride, oxidation with potassium permanganate, and numerous other impracticable ideas that had been tried only on paper. The ordinary refiner distils over scrap iron and refines with alkaline lead oxide. From much the greater part of refining oil sulphur is removed by distilling over heated copper oxide and recovery of the oxide, a process that is said to have originated in Canada, but is known as the Frasch process. Probably fifty tons of sulphur daily is a conservative estimate of the amount extracted from Ohio oil and burned off into the atmosphere. It is claimed for this process that it is capable of removing the sulphur to 0.02 per cent., which is probably correct. Excellent burning oils are made from Ohio petroleum.

The composition of Ohio petroleum, so far as the portions readily distilled are concerned, has only been arrived at within the last few months. Several years ago an examination of the sulphur petroleums, as Ohio and Canadian petroleum was then designated, showed that the series C_nH_{2n+2} formed the portions of Ohio crude

oil which distilled below 212°, and the same members were discovered that had been previously identified in Pennsylvania oil, although the proportion of these hydrocarbons was smaller than in Pennsylvania oil. The proportion of aromatic hydrocarbons is higher in Ohio than in Pennsylvania oil. The lower methylenes are also probably contained in larger proportion in the Ohio oil. An investigation just finished on the hydrocarbons contained in the limits between 112° and 280°, tension 30 mm., has identified thirteen hydrocarbons, with very satisfactory data on the proportions of carbon and hydrogen which establish the series, and the molecular weights and indices of refraction which identify the members of the series. The following hydrocarbons of the series C_nH_{2n} were found: $C_{12}H_{24}$, $C_{13}H_{26}$, $C_{14}H_{28}$, $C_{15}H_{30}$, $C_{16}H_{32}$, $C_{17}H_{34}$. Unfortunately the distillate that should yield the hydrocarbon $C_{18}H_{36}$ was lost, although its specific gravity was ascertained before filtration.

Of the series C_nH_{2n-2}, the following hydrocarbons were identified: $C_{19}H_{36}$, $C_{20}H_{38}$, $C_{21}H_{40}$, $C_{22}H_{42}$; and of the series C_nH_{2n-4}, the hydrocarbons $C_{23}H_{42}$, $C_{24}H_{44}$, $C_{25}H_{46}$.

The change in series is attended with a greater difference in specific gravity between adjacent hydrocarbons; for instance, the last change in series is very marked, as the following table shows:

Distillate.	*Sp. Gr.*	*Hydrocarbon.*	*Difference in Sp. Gr.*
224–227°	.8614	$C_{21}H_{40}$	
237–240°	.8639	$C_{22}H_{42}$	.0025
253–255°	.8842	$C_{23}H_{42}$	.0225
263–265°	.8864	$C_{25}H_{48}$	.0022

The distillates from which these hydrocarbons were separated above 150°, 30 mm., contained a large proportion of solid paraffine. The higher fractions were solid at ordinary temperatures, but no attention was given to the solid constituents, for without doubt they are identical with the solid hydrocarbons identified in Pennsylvania oil. Much difficulty was met with in separating the liquid constituents. The distillate was first cooled to 0° and filtered, and the filtrate then cooled to —10° and again filtered.

In purifying these heavy oils they were first dissolved in gasoline, and after purification the gasoline was removed by distillation. The greater preponderance of the series poorer in hydrogen in Ohio oil over Pennsylvania oil explains the higher specific gravity

of Ohio crude oil. The series C_nH_{2n-4} does not appear in Pennsylvania oil within the range of distillates below 300°, but it does appear in Ohio oil. The proportions of the series still poorer in hydrogen in the residues of distillation from Ohio oil are doubtless still greater.

Canadian Corniferous Limestone Petroleum.

In the paper referred to above, the composition of the distillates from Canadian oil was explained, including the hydrocarbons $C_{11}H_{22}$ and $C_{12}H_{24}$, which were identified in the fractions 196° and 214°. This limits the series C_nH_{2n+2} in Canadian oil to the lower members. Two years ago the higher fractions were examined for the individual hydrocarbons and results obtained, not yet published, that show a continuation of the series C_nH_{2n}; and the hydrocarbons separated included the following: $C_{12}H_{24}$, $C_{13}H_{26}$, $C_{14}H_{28}$, $C_{15}H_{30}$, $C_{16}H_{32}$.

These bodies were identified by combustion for the series, and their molecular weights ascertained for the individual members of the series; the specific gravity of each hydrocarbon agrees closely with that of the corresponding hydrocarbon of Ohio petroleum. These values were still further confirmed by the formation and analysis of the chlorides.

The proportions of the lower members of the series C_nH_{2n+2}, which form the naphtha and gasoline in Canadian petroleum, is considerably smaller than in Ohio petroleum. The proportion of burning oil distillates is also less, and it is not possible to make from Canadian oil so good burning oil. The series C_nH_{2n} shows less stability on standing than the higher series C_nH_{2n+2}. I have samples of burning oil from Canadian petroleum that have stood ten years; they have changed from "water white," the original quality of the oil, to very dark yellow. Much larger quantities of gas are evolved in refining the Canadian oil, which is run back for heating the stills. Some paraffine is made, but the yield is small. The sulphur in the crude oil gives much trouble in refining, and it is not all removed in the burning oil. The percentage of sulphur is higher than in Ohio petroleum as a rule, usually about one per cent. Canadian petroleum should give good grades of lubricators, but I have never examined these products.

California Petroleum.

In a paper published two years ago the composition of California petroleum oil from different sections of those fields was explained, and the principal series in the range of distillates examined, which included those below 214° in all specimens of crude oils, showed the series C_nH_{2n}.

Allusion was made in the former publication to a specimen of exceptionally heavy oil from Summerland, Santa Barbara county, of especial interest, since it came from wells sunk below the level of the Pacific Ocean at high tide. No distillates were collected from this oil below 200° atmospheric pressure. Under a tension of 60 mm. continued fractional distillation separated very heavy oils that were colorless or slightly yellow. They were purified by dissolving in gasoline and agitating with sulphuric acid, common and fuming, and the gasoline distilled off with the aid of a current of carbonic dioxide. The composition of these products proved to be very different from that of the other California oils, or from any others we have examined. For instance, the fraction 210°–215°, 60 mm., gave as its specific gravity at 20°, 0.9085, and the proportions of carbon and hydrogen corresponded to the hydrocarbon $C_{19}H_{34}$, or the series C_nH_{2n-4}. The higher members were the most viscous distillates that we have separated in what appears to be a pure form from any petroleum.

So far as we have carried the examination of California petroleum, no solid paraffine hydrocarbons have been found. From several fields oil has been obtained whose higher distillates on standing deposited large well-defined crystals, but unlike paraffine. From the fractions between 275° and 295°, 60 mm., separated from Torrey cañon oil, a considerable quantity of crystals separated on standing several months that melted at 57° to 62°. These crystals were readily soluble in benzol and alcohol, and crystallized from hot alcohol on cooling apparently in a pure form, unlike the solid paraffine hydrocarbons that are very sparingly soluble in alcohol; sufficient of this product for complete identification has not yet been obtained. The higher portions of heavy California petroleum offer an attractive field for study of the series poorer in hydrogen.

Texas Petroleum.

Much attention has been attracted to the recent discoveries of oil in Texas, and in some respects these deposits of oil possess a

peculiar interest. The older Corsicana field yields an oil that is adapted for the preparation of a fairly good grade of burning oil, but it is inferior to Pennsylvania oil, since, as Richardson has shown, it is composed chiefly of the methylene hydrocarbons. The heavier oil at Beaumont does not yield a sufficient proportion of burning oil distillate to make its preparation economical, but it is stated that a distillate can be separated in small quantities without cracking that can be refined into an inferior grade of burning oil. So far as examined the Beaumont oil does not contain members of the series C_nH_{2n+2}, which is essential in oils that yield the best grades of kerosene. The unique occurrence of this crude oil, underlying beds of sulphur under rather loose beds of shale, should exclude any of the most volatile constituents, such as are found in Pennsylvania oil. As we have demonstrated, the predominating series of hydrocarbons include the methylenes and condensed series. The crude oil is very heavy; it easily decomposes under distillation, but by exclusion of air very heavy distillates may be separated without decomposition, from which superior lubricating oils may be prepared, especially of the heaviest type. The heaviest residue from Beaumont oil, if decomposition has been prevented, forms the best sort of petroleum asphalt, much heavier than similar products to be obtained from any other than California crude oil; in fact all the products to be obtained from Texas oil resemble those prepared from California oil.

The sulphur compounds in Texas oil seem to be much less stable than those in Ohio and Canadian oils, perhaps on account of their higher molecular weight. It is worthy of note that heavy petroleum, such as that from Texas and California fields, contain more sulphur than more volatile crude oils, like the Pennsylvania.

Petroleum from other fields, such as Colorado, Wyoming, Japan and South America, all partake of the properties of the heavier products from the fields in this country. The Japanese crude oils were very carefully sampled for our examination three years ago. There is promise of a great development of oil territory in South America. I scarcely believe that the sample of heavy oil we examined some years ago represents the true condition of the oil fields there. The heavy petroleums are rapidly increasing in value as fuel. Prices have recently been advanced in Texas to seventy-five cents per barrel.

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I have a large amount of unpublished data on the sulphur and nitrogen compounds in petroleum. Although I have had the sulphur compounds under examination for nineteen years, I am not yet sure as to the form of the higher series. In a paper presented to the New York Section of the Society of Chemical Industry two years ago, and published in the *Society Journal*, a brief account of the sulphur and nitrogen compounds was given. It was explained that these bodies are members of a series $C_nH_{2n}S$, and that they oxidize into sulphones and very readily into sulphuric acid. These bodies are doubtless ring compounds, as was then suggested, similar to the thiophenes.

California petroleum contains a larger proportion of nitrogen base than any other, so far as known. Two per cent. of nitrogen, the amount contained in several specimens of crude oils examined, corresponds to twenty or twenty-five per cent. of the basic oils, or about one-quarter of the crude oil consists of the nitrogen compounds. In structure these bodies are tetra- or octohydro-ring compounds in homologous series. The tetrahydro-condition is shown by their instability.

It is, therefore, apparent that a similar condition of instability prevails in the methylenes, and in the sulphur and nitrogen compounds from heavy petroleum. The sulphur and nitrogen bodies are found in considerable quantities only in such petroleum as is mainly composed of the methylenes or series poorer in hydrogen.

Another interesting series of bodies found in California, but not in Eastern oils, at least to the same extent, are the phenols, which are present in considerable quantities in some of the California oil.

Natural Formation of Petroleum.

Much as has been said on this attractive subject, a broader knowledge of facts is necessary before definite conclusions can be reached. What is known forms the basis for only one explanation concerning the formation of petroleum, and that is that it was formed from vegetable or animal matter by slow decay or breaking down from the complex forms of vegetable or animal life under the influence of natural forces, with no great elevation in temperature such as is necessary for distillation.

Mendelejeff's theory of the formation from carbides at high temperatures, recently asserted with greater force on the basis of

Moissan's work with the electric furnace, demands too many hypothetical assumptions, and it has too little support on the basis of fact. To reason from the artificial formation of alloys and carbides in an electric furnace to the natural formation of petroleum containing nitrogen, sulphur and oxygen, in the form of hydrothophenes, hydrochinolines, and phenols, demands a too broad reach of the imagination to make the connections.

Bearing in mind the fact that petroleum may now be regarded as one and the same substance whatever its source, and that the deposits in different fields are composed of the same series, differing only in the proportions of these constituents, it must be admitted that it had one origin and one only. With reference to the series of hydrocarbons, it is immaterial whether its source was animal or vegetable, for under the influence of natural agencies it could have been formed as well from one as from the other.

This question has been attacked on chemical grounds from the wrong direction. Because hydrocarbons of the marsh gas series, ethylene series or acetylene series at temperatures of decomposition form minute quantities of the aromatic series, or that hexahydroaromatic bodies are formed from the aromatic hydrocarbons by heating with hydriodic acid, to assume that these same changes were produced by natural agencies and resulted in the formation of the hydrocarbons which now constitute petroleum, together with the other constituents of petroleum, ascribes to these natural agencies a direction of action and power that we do not know they possess.

In considering present knowledge with reference to the natural formation of petroleum, it seems to me that the following questions must be answered:

1. What is the chronology of petroleum: in what order were the deposits formed in different fields?

2. Were the least volatile constituents formed from the most volatile or the reverse?

3. What is a reasonable explanation of the formation of the other constituents of petroleum?

The first question must be answered by the geologist.

It is natural to assume that the limestones formed by the accumulation of the shell remains of animal life were deposited first from the ancient sea. The sandstones, as products of erosion from the older rocks, were deposited last. The question as to whether the

different deposits of petroleum were formed *in situ*, or formed in other strata and by some natural agency transferred to their present location, has not I believe been satisfactorily answered by the geologists. In the case of the limestone petroleum, it would seem that it must have been formed where it is now to be found, as Hunt and Orton have ably maintained.

The theory of distillation from some other strata is not tenable in the light of present knowledge of the constituents of petroleum. Neither could any known constituents of plants that could form petroleum be distilled, nor could the heavier portions of petroleum be distilled; the result would be only very volatile distillates and deposits of coal or graphite. In this condition deposits of petroleum should always be accompanied by coal, or with coal in the near vicinity.

In the case of Pennsylvania and the allied southern Ohio and West Virginia petroleum, it would be a great discovery to connect these deposits with the coal formations, for then the source would unquestionably be vegetable growth and would support the prevailing opinion that this was the source of petroleum of this class. It is reasonable to assume, as is now believed, that Pennsylvania oil was not formed in the sandstones, but found its way there by natural agencies from lower strata, probably the Devonian shales. The infiltration of the crude oil through sandstones would have a purifying effect. It is quite probable that the very light yellow crude oils from the Berea Grit and other sandstones were filtered a second time or more into their present positions.

With reference to the source of the limestone oils, the evidence is all in favor of animal origin, and the same is true of California oil, although its formation is probably far more recent than that of the others. Texas petroleum has not been sufficiently studied in relation to its occurrence and composition, but it is evidently of more recent origin, like California oil.

With reference to the second question, is it more reasonable to assume, for instance, that the solid paraffine hydrocarbons were formed from the lower members of this series, or that the lower members were formed from paraffine? On this point some experimental evidence may be brought to bear. Reichenbach obtained paraffine from both vegetable and animal organic matter. Engler obtained paraffine by the distillation of fish oil, as Warren and Storer had done many years previously.

It is well known that paraffine breaks down very readily into hydrocarbons with lower molecular weights, but it is not possible to polymerize the lower hydrocarbons into the solid paraffine hydrocarbons. The tendency in cracking of any constituents of petroleum is toward the formation of the lower series and finally carbon in the form of coke. So far as experimental evidence and observation have shown the nature and relations of the hydrocarbons which compose the different series in petroleum, the conclusion is convincing that the lower members of the series were formed from the higher. A single break in the ring of a methylene is sufficient to form by the addition of hydrogen a paraffine hydrocarbon.

In answer to the third question, as to the formation of the sulphur, nitrogen and oxygen compounds in petroleum, these bodies have evidently not been built up synthetically, but are the products of decomposition of more highly organized constituents of organic bodies. It would seem that the small proportions of these bodies in Pennsylvania oil, as compared with the larger proportions in the limestone oils and California oil, should be strong evidence in favor of a different origin, that Pennsylvania oil came from organic vegetable remains, which should permit of the small amounts of sulphur and nitrogen compounds found in this class of oils.

But I think it can be asserted as a fact that the very large proportion of nitrogen compounds in California petroleum, amounting to one-fifth or more of the total weight of the oil, can only be accounted for by accepting animal remains as the source of their formation. As a summation of what is at present known of the origin of petroleum, the following answers may be given to the questions propounded above:

1. Petroleum containing large proportions of the volatile hydrocarbons, especially of the series C_nH_{2n+2}, such as Pennsylvania petroleum, was formed from vegetable organic matter. The limestone petroleum and California petroleum was formed from organic matter of animal origin.

2. Cellulose, starch and other similar bodies in plants, and the fats and nitrogen compounds in animal bodies, by gradual decomposition with exclusion of air, gave first the heavier bodies found in petroleum, and by natural agencies during long periods of time, with no considerable rise in temperature, further decomposition included as products the hydrocarbons with smaller molecular weights.

3. The nitrogen and sulphur constituents of petroleum could only have been formed directly from or through the agency of animal organic matter.

There is an attractive field for the chemical geologist to study, more intimately than has ever been done, the occurrence of petroleum in connection with its composition.

CLEVELAND, O.

THE FORWARD MOVEMENT IN PLANT-BREEDING.

BY L. H. BAILEY.

(*Read April 2, 1903.*)

The first specific interest in cultivated plants was in the gross kinds or species. As the contact with plants became more intimate, various indefinite form-groups were recognized within the limits of the species. Gradually, with the intensifying of domestication and cultivation, very particular groups appeared and were recognized. These smaller groups came finally to be designated by names, and the idea of the definite and homogeneous cultural variety came into existence. The variety-conception is really a late one in the development of the human race. It is practically only within the past two centuries that cultivated varieties of plants have been recognized as being worthy of receiving designative names. It is within this period, also, that most of the great breeds of animals have been defined and separately named.

All this measures the increasing intimacy of our contact with domesticated plants and animals. It is a record of our progress. The peoples that are most advanced in the cultivation of any plant are the ones that have the most named varieties of that plant. In Japan, to this day, the plums pass under ill-defined class-names. We have introduced these classes, have sorted out the particular forms that promise to be of value to us and have given them specific American names. Not long ago a native professor in Japan wrote me asking for cions of these plums, in order that he might introduce Japanese plums into Japan. The Russian apples are designated to some extent by class-names; in fact, it was not until the appearance of Regel's work, about a generation ago, that Russian pomology may be said to have been born. What

constitutes a variety is increasingly more difficult to define, because we are constantly differentiating on smaller points. The growth of the variety-conception is really the growth of the power of analysis.

The earlier recognized varieties seem to have come into existence unchallenged. There is very little record of inquiry as to how or why or even where they originated. That is, the quest of the origin arose long after the recognition of the variety as a variety. Even after inquisitive search into origins had begun there was little effort to produce these varieties. The describing of varieties and the search into their histories was a special work of the nineteenth century. One has only to consult such American works as Downing's *Fruits and Fruit Trees of America* and Burr's *Field and Garden Vegetables of America*, to see how carefully and methodically the descriptions and synonymy of the varieties were worked out. These are types of excellent pieces of editorial and formal systematic work.

There have been isolated efforts at producing varieties for many years. These efforts began before the time of the general discussion of organic evolution. In fact, it was on such experiments that Darwin drew heavily in some of his most important writings. Roughly speaking, however, the conception that the kinds of plants can be definitely modified and varied by man is a product of the last half century. We now believe that there is such a possibility as plant-breeding. It is really a more modern conception, so far as its general acceptance is concerned, than animal-breeding. But both animal-breeding and plant-breeding are the results of a new attitude toward the forms of life—a conviction that the very structure, habits and attributes are amenable to change and control by man. This is really one of the great new attitudes of the modern world.

Formerly, and even up to the present time, the variety has been taken as the unit for plant-breeding work, as it has been for descriptive and classificatory work. Whether we believed it or not, we have accepted it as a fairly definite thing or entity. Yet, what is a variety? Only the ideal of one man or a set of men. Custom may define its boundaries, but in fact it has no boundaries. At best, a variety is only an assemblage of forms that agree rather more than they differ: and any one of these forms may, with equal propriety, be called another variety. Shall we continue to

consider the variety as a unit or basis from which we are to breed for the purpose of producing other varieties? Or shall we still further refine our ideals and find that the variety-conception is really only a mark of an imperfect and superficial development of an immature age?

Now, plant-breeding is worthy of the name only as it sets definite ideals and is able to attain them. Merely to produce new things is of no merit: that was done long before man was evolved. A child can "produce" a new variety, but it may learn nothing and contribute nothing in producing it. I have myself produced 1500 new kinds of pumpkins and squashes, but I had no idea what I was to produce, the world is no better for my having produced them, and I am no wiser (except in experience) than I was before. In many "new" things that are produced, there may be dispute as to whether they are new and as to whether they are distinct enough to be named and therefore to be ranked as varieties at all. This is not science, nor even breeding: it is playing and guessing. What does the world care whether John Jones produces "Jones' Giant Beardless wheat"? But it does care if he produces a wheat having a half of one per cent. more protein. We must give up the production of mere "varieties"; we must breed for certain definite attributes that will make the new generations of plants more efficient for certain purposes: this is the new outlook in plant-breeding.

Happily, we are not without abundant accomplishment in this new field. The last ten years has seen a remarkable specialization in the producing of plants that are adapted to particular needs. The days of merely crossing and sowing the seeds to see what will turn up are already past with those who are engaged seriously in the work. The old method was hit-and-miss and the result was to take what good luck put in your way: the new method proceeds definitely and directly and the result is the necessary outcome of the line of effort. The crux of the new ideal is efficiency in one particular attribute in the product of the breeding. These attributes are measurable: the kind of results are foreseen in the plan, or are predictable.

All these remarks are typically illustrated in the experiments with corn-breeding conducted in Illinois. It is significant to note what are the reasons for breeding new corns, as stated by Professor Hopkins in Bulletin 82 of the Illinois Experiment Station:

"In its own publication a large commercial concern, which uses enormous quantities of corn, makes the following statements:

"'A bushel of ordinary corn, weighing fifty-six pounds, contains about four and one-half pounds of germ, thirty-six pounds of dry starch, seven pounds of gluten, and five pounds of bran or hull, the balance in weight being made up of water, soluble matter, etc. The value of the germ lies in the fact that it contains over forty per cent. of corn oil, worth, say, five cents per pound, while the starch is worth one and one-half cents, the gluten one cent, and the hull about one-half cent per pound.

"'It can readily be seen that a variety of corn containing, say, one pound more oil per bushel would be in large demand.

"'Farmers throughout the country do well to communicate with their respective agricultural experiment stations and secure their co-operation along these lines.'

"These are statements and suggestions which should, and do, attract the attention of experiment station men. They are made by the Glucose Sugar Refining Company of Chicago, a company which purchases and uses, in its six factories, about fifty million bushels of corn annually. According to these statements, if the oil of corn could be increased one pound per bushel, the actual value of the corn for glucose factories would be increased five cents per bushel; and the president of the Glucose Sugar Refining Company has personally assured the writer that his company would be glad to pay a higher price for high oil corn whenever it can be furnished in large quantities. The increase of five cents per bushel on fifty million bushels would add $2,500,000 to the value of the corn purchased by this one company each year. The glucose factories are now extracting the oil from all the corn they use and are unable to supply the market demand for corn oil. On the other hand, to these manufacturers protein is a cheap by-product and consequently they want less protein in corn.

"Corn with a lower oil content is desired as a feed for bacon hogs, especially for our export trade, very extensive and thorough investigations conducted in Germany and Canada having proved conclusively that ordinary corn contains too much oil for the production of the hard firm bacon which is demanded in the markets of Great Britain and Continental Europe."

It is very interesting to note that this does not mention the improvement of Leaming's White, or Jones' Yellow Dent, or any

other named variety of corn, nor does it propose that any new variety shall be created. It suggests what may be done with any variety of corn. The experiments in Illinois demonstrate that "the yield of corn can be increased, and the chemical composition of the kernel can be changed as may be desired, either to increase or to decrease the protein, the oil, or the starch."

The breeding of the corn proceeds along two general lines—for physical perfection and for chemical perfection. Selection for physical merit proceeds as follows, to quote again from Professor Hopkins: "The most perfect ears obtainable of the variety of corn which it is desired to breed should be selected. These ears should conform to the desirable standards of this variety and should possess the principal properties which belong to perfect ears of corn, so far as they are known and as completely as it is possible to secure them. These physical characteristics and properties include the length, circumference, and shape of the ear and of the cob; the number of rows of kernels and the number of kernels in the row; the weight and color of the grain and of the cob; and the size and shape of the kernels. In making this selection the breeder may have in his mind a perfect ear of corn and make the physical selection of seed ears by simple inspection, or he may make absolute counts and measurements and reduce the physical selection almost to an exact or mathematical basis."

The selection for chemical content is made on two bases—on the general gross structure of the corn kernel as determined by "mechanical examination," and on chemical analysis of the kernel.

Chemical examination by means of mechanical examination is as follows:

"The selection of seed ears for improved chemical composition by mechanical examination of the kernels is not only of much assistance to the chemist in enabling him to reduce greatly the chemical work involved in seed corn selection, but it is of the greatest practical value to the ordinary seed corn grower who is trying to improve his seed corn with very limited service, if any, from the analytical chemist. This chemical selection of seed ears by mechanical examination, as well as by chemical analysis (which is described below), is based upon two facts:

"1. That the ear of corn is approximately uniform throughout in the chemical composition of its kernels.

"2. That there is a wide variation in the chemical composition of different ears, even of the same variety of corn. These two facts are well illustrated in Table 1.

TABLE I. PROTEIN IN SINGLE KERNELS.

		Ear A, protein, per cent.	*Ear B, protein, per cent.*	*Ear C, protein, per cent.*	*Ear D, protein, per cent.*
Kernel No.	1	12.46	11.53	7.45	8.72
" "	2	12.54	12.32	7.54	8.41
" "	3	12.44	12.19	7.69	8.73
" "	4	12.50	12.54	7.47	8.31
" "	5	12.30	12.14	7.74	9.02
" "	6	12.49	12.95	8.70	8.76
" "	7	12.50	12.84	8.46	8.89
" "	8	12.14	[1]	8.69	9.02
" "	9	12.14	12.04	8.86	8.96
" "	10	12.71	12.75	8.10	8.89

"It will be observed that while there are, of course, small differences among the different kernels of the same ear, yet each ear has an individuality as a whole, the difference in composition between different ears being much more marked than between different kernels of the same ear.

"The uniformity of the individual ear makes it possible to estimate or to determine the composition of the corn by the examination or analysis of a few kernels. The remainder of the kernels on the ear may then be planted if desired. The wide variation in the composition between different ears furnishes a starting-point for the selection of seed in any of the several different lines of desired improvement.

"The methods of making a chemical selection of ears of seed corn by a simple mechanical examination of the kernels is based upon the fact that the kernel of corn is not homogeneous in structure, but consists of several distinct and readily observable parts of markedly different chemical composition (see illustrations). Aside from the hull which surrounds the kernel, there are three principal parts in a grain of corn:

"1. The darker colored and rather hard and horny layer lying next to the hull, principally in the edges and toward the tip end of the kernel, where it is about three millimeters, or one-eighth of an inch, in thickness.

[1] Determination lost by accident.

"2. The white, starchy-appearing part occupying the crown end of the kernel and usually also immediately surrounding, or partially surrounding, the germ.

"3. The germ itself which occupies the central part of the kernel toward the tip end.

"These different parts of the corn kernel can be readily recognized by merely dissecting a single kernel with a pocket-knife, and it may be added that this is the only instrument needed by anybody in making a chemical selection of seed corn by mechanical examination.

"The horny layer, which usually constitutes about sixty-five per cent. of the corn kernel, contains a large proportion of the total protein in the kernel.

"The white, starchy part constitutes about twenty per cent. of the whole kernel, and contains a small proportion of the total protein. The germ constitutes only about ten per cent. of the corn kernel, but while it is rich in protein, it also contains more than eighty-five per cent. of the total oil content of the whole kernel, the remainder of the oil being distributed in all the other parts.

"By keeping in mind that the horny layer is large in proportion, and also quite rich in protein, and that the germ, although rather small in proportion, is very rich in protein, so that these two parts contain a very large proportion of the total protein in the corn kernel, it will readily be seen that by selecting ears whose kernels contain more than the average proportion of germ and horny layer, we are really selecting ears which are above the average in their protein content. As a matter of fact, the method is even more simple than this, because the white, starchy part is approximately the complement of, and varies inversely as, the sum of the other constituents; and to pick out seed corn of high protein content it is only necessary to select those ears whose kernels show a relatively small proportion of the white, starchy part surrounding the germ.

"As more than eighty-five per cent. of the oil in the kernel is contained in the germ, it follows that ears of corn are relatively high or low in their oil content according as their kernels have a larger or smaller proportion of germ.

"In selecting seed corn by chemical analysis, we remove from the individual ear two adjacent rows of kernels as a representative sample. This sample is ground and analyzed as completely as may

be necessary to enable us to decide whether the ear is suitable for seed for the particular kind of corn which it is desired to breed. Dry matter is always determined in order to reduce all other determinations to the strictly uniform and comparable water-free basis. If, for example, we desire to change only the protein content, then protein is determined. If we are breeding to change both the protein and the oil, then determinations of both of these constituents must be made."

Any careful farmer can make such examinations as these. The relative abundance of one or the other of the three areas in the kernel will indicate what ears should be chosen for seed. Professor Hopkins proposes a system of field trials in which one ear furnishes plants for one row, thereby allowing the operator to see and measure the individuality of each ear. By choosing ears that most nearly approach the ideal, and then by continued selection year by year, the desired result is to be secured and maintained.

It is impossible to overestimate the value of any concerted corn-breeding work of this general type. The grain alone of the corn crop is worth about one billion dollars annually. It is no doubt possible to increase this efficiency by more than one per cent.

An interesting cognate inquiry to this direct breeding work is the study of the commercial grades of grains. It is a most singular fact that the dealer's "grades" are of a very different kind from the farmer's "varieties." In the great markets, for example, corn is sold as "Yellow No. 1," "Yellow No. 2," "Yellow No. 3." Any yellow corn may be thrown into these grades. What constitutes a grade is essentially a judgment on the part of every dealer. It so happens that the grade tends to deteriorate as the grain reaches the seaboard, for the tendency of each dealer is to mix with the better grades just as much of an inferior grade as will allow the carload or cargo to pass the inspector's examination. The result is that the grain is likely to be condemned or criticised when it reaches Liverpool. Complaints having come to the Government, the United States Department of Agriculture has undertaken to determine how far the grades of grain can be reduced to indisputable instrumental measurement. This work is now in the hands of Mr. Scofield, in the Division of Botany. The result is likely to be a closer defining of what a grade is; and this point once determined, the producer will make an effort to grow such grain as will grade to No. 1, and thereby reach the extra

price. Eventually the efficiency points of the grower and the commercial grades of the dealer ought nearly or quite to coincide. There should come a time when corn is sold on its inherent merits, as, for example, on its starch content. This corn would not then be graded 1, 2 and 3 on its starch content, because that content would be assured in the entire product; but the Grade 1 would mean prime physical condition, and the lower grades inferior physical condition. Eventually something like varietal names may be attached to those kinds of corns that, for example, grade fifteen per cent. protein. The name would be a guarantee of the approximate content, as it now is in a commercial fertilizer.

Closely allied to the corn-breeding work of Illinois (which is carried on by the Experiment Station and also by a commercial firm organized for that purpose) is the wheat-breeding and flax-breeding work in Minnesota under the direction of Professor Hays. Mr. Hays' aim has been chiefly to increase productiveness. The following sketch is made from his notes:

"Here are three examples of increased efficiency produced at the Minnesota Experiment Station in co-operation with the U. S. Bureau of Plant Industry.

"Minn. No. 163 wheat was bred by selection from Fife parentage. During three years' comparison in field tests at University Farm, near Minneapolis, it averaged 2.7 bushels gain per acre, or eleven per cent., better than its parent variety, as shown by the following table:

Minn. No. 163	28.5	bushels.
Fife parent	25.8	"
Increase	2.7	"

"In 1899, this wheat was sold to one hundred farmers, thirty-eight of whom made the comparison between this and their common wheats in a manner fair to both. The following table shows the average increased yield to have been 1.4 bushels per acre, or eight per cent.:

Minn. No. 163, average yield	18.1	bushels.
Common wheats, average yield	16.7	"
	1.4	"

"Minn. No. 169 wheat was bred by selection from a Blue Stem

foundation. During the first four years that it was in our field tests it averaged 4.9 bushels more than the parent wheat, as displayed by the following table of average yields, showing an increase over its parent variety of more than twenty per cent.:

Minn. No. 169	28.5	bushels.
Minn. No. 51	23.6	"
Gain	4.9	"

"In 1902, this wheat was sent in four-bushel lots, at $1.50 per bushel, to three hundred and seventy-five farmers. Eighty-nine reports gave comparisons that were fair both to the new and old wheats, and there were obtained the following average yields, showing an increase over the common wheats of the entire State of eighteen per cent. If this increase could be applied to one-tenth of the area of the wheat crop in Minnesota, the increased yield would be worth over a million dollars:

Minn. No. 169	21.5	bushels.
Common wheats	18.2	"
Increase	3.3	"

"The third example is even more pronounced. Seven years ago Prof. Hays chose seven samples of the common Minnesota and Dakota flax, and made by selection many new types for the production of seed, and numerous other types especially for production of fibre. The following table gives the general results:

	Yield of grain.	*Yield of straw.*	*Height in inches.*
Av. of 4 best varieties selected for seed	17.8	1.40	23
Av. of 4 best varieties selected for fibre	10.5	1.76	35
Av. of 4 best common varieties (from outside sources)	11.9	1.52	24
	5.9	.24	....

"Here in field trials, in 1902, the increased yield per acre of the new varieties bred for seed is forty-nine per cent.; and the increased height of the new varieties bred for fibre is forty-six per cent. more than the common flax."

"We have developed statistical methods," Professor Hays writes, "of dealing with such plants as wheat, alfalfa, corn, and,

in fact, nearly all of the field crops where it is necessary or very advantageous to grow or plant in a hill, that selections may be made and the breeding powers of parent plants measured. The general features of this statistical work may be stated as follows: Every acquisition or newly-bred variety receives a number written thus, 'Minn. No. 13 corn,' for example. It is also botanically described and the facts concerning its history, name, description, etc., entered in our *Minnesota Number Book*. If the newly-secured variety is an exceptionally promising one it is put into field tests, but ordinarily in the preliminary garden test the first year. Promising acquisitions and promising newly-bred hybrid stocks are entered in the nursery, where their breeding by rigid selection is begun, and large numbers of plants are grown, one in each hill, giving each plant the same space and opportunities as each other plant. By processes of elimination, the few best performers are secured. The next year we plant a large number of the progeny of each of these superior mother-plants. The average yield, height and other measures are taken of the progeny of each mother-plant. These tests of the breeding values of the mother-plants are continued two and sometimes three years. Seeds from parent plants producing the best average progeny are used alone or in mixtures of close-pollinated species, and in mixtures in open pollinated species as the foundation of new varieties. These are tested in the field with the parent and other best standard varieties for three years. Any introduced or newly-bred variety which is an especially good yielder of value per acre is sent to the co-operating State Experiment Stations in surrounding States and to our sub-stations, and its quantity is rapidly increased. Any variety that is specially promising after being tried for, say, two years at several stations is increased to sufficient quantity to sell to a number of farmers in each county in the State. This seed, backed by all the force of pedigree that we can command, is sold at a high price, so as to make the seed business profitable, and men are induced to raise it and sell large quantities at a price which will yield them a profit. In this way our first new wheat will be planted on hundreds of thousands of acres this year, and other new things are being widely disseminated."

A most gratifying augury of this coming type of effort is to be found in the work of the Plant-Breeding Laboratory of the national Department of Agriculture. This is an organization effected for

the purpose of producing types or kinds of plants that shall meet particular requirements. Its work is now proceeding with many groups of plants, but the burden of all its effort is efficiency in the final product. Its work with cotton promises to do nothing less than to revolutionize the cotton industry. The special difficulty with the present Upland cotton is the shortness of the "staple" or fibre. This inch-long staple sells at present (1903) for eight to eight and one-quarter cents a pound, whereas the long staple of the Sea Island cotton sells for twenty-five to thirty cents per pound. The effort is to secure a longer staple for the Upland, either by crossing it with the Sea Island or by working with some foreign long-staple type. The Egyptian cotton has a long staple, and this is now being used as one of the foundation stocks. But the Egyptian cotton possesses faults along with its long staple. It will be the work of years' by means of careful selection, to augment or maintain the desirable qualities and to eliminate the undesirable qualities; when this is done, the cotton will no longer be the Egyptian, but practically a new creation, and this new creation should receive a new name in order to distinguish it from the inferior Egyptian from which it will have had its birth. Under the leadership of Mr. Webber, this new plant-bleeding enterprise (probably the largest in the world) is now extended to citrous fruits, apples, pineapples, oats, tobaccos and other crops; and there is every indication that its usefulness will expand greatly within the immediate future. Other institutions, and other divisions of the Department of Agriculture, are conducting similar work. Time is now on when every resourceful farmer must look to the improving of the intrinsic merits of his crops.

The modern methods of plant-bleeding demand, first, that the breeder shall familiarize himself thoroughly with the characteristics of the group of plants with which he is to work. He must have very specific and definite knowledge of what makes the plant valuable and what its shortcomings are. Then he must secure as starting-points plants that give promise in the desired direction. Thereafter his skill will be taxed in selecting along responsive lines, making accurate and significant statistical measures, in devising workable systems of testing. He must grow large numbers of plants, if he is working with farm crops, in order to multiply his chances of securing desirable variations and to minimize the errors.

A promising course of breeding is one that shall develop disease-

resisting races within the variety. Considerable progress has already been made in this direction with cotton, oats and some other crops. Now and then a hill or a row or a variety of potato resists the blight. Why? May it not be used as a starting-point for the development of a blight-resistant strain? The development of disease-resisting and pest-resisting races is one of the most promising developments in the new plant pathology.

Nor are all these advances to be secured from seed selection alone. The cuttings and grafts of fruit plants perpetuate the parental characteristics with a good degree of surety. The time must soon come when it will not be sufficient to multiply the Bartlett pear from the Bartlett pear. We shall still further specialize our ideals and propagate from particular Bartlett pear trees that have made record performances. This subject is being tested in New York and elsewhere. It is one of the most important problems now before the nurseryman and orchardist.

All this plant-breeding work is especially of a kind to demand governmental support. The progress of invention can be left to private initiative, because the person can patent his device and secure all the financial returns that it is worth. A variety cannot well be patented or controlled. This is particularly true of these great race-improvements, in which no distinct and namable variety results; and these race improvements are the very ones that are most likely to be of greatest benefit to agriculture and therefore to the nation.

These methods and ideals may all be summed up as follows:

I. To determine on what the merit in any group of plants depends, and to find out what is needed to make the plants more efficient. What makes a potato "mealy"?

II. Securing a start in the desired direction by

(*a*) Choosing for seed-bearing any plants that are promising;

(*b*) Introducing prominent foundation-stock from other regions or other countries;

(*c*) Crossing for the purpose of injecting a new or better character into the strain.

III. Continued selection, careful testing and accurate statistical measurements and records to keep the progress true to line.

The first thing that strikes one in all this new work is its strong contrast with the old ideals. The "points" of the plants are those of "performance" and "efficiency." It brings into sharp relief

the accustomed ideas as to what are the "good points" in any plant, illustrating the fact that these points are for the most part only fanciful, are founded on *a priori* judgments, and are more often correlated with mere "looks" than with efficiency. An excellent example may be taken from corn. In "scaling" any variety of corn, it is customary to assume that the perfect ear is one nearly or quite uniformly cylindrical throughout its length and having the tip and butt well covered with kernels. In fact, the old idea of a good variety of corn is one that bears such ears. Now this ideal is clearly one of perfection and completeness of mere form. We have no knowledge that such form has any correlation with productiveness, hardiness, drought-resisting qualities, protein or starch content—and yet these attributes are the ones that make corn worth growing at all. An illustration also may be taken from string beans. The ideal pod is considered to be one of which the tip-projection is very short and only slightly curved. This apparently is a question of comeliness, although a short tip may be associated in the popular mind with the absence of "string" in the pod; but we do not know that this character has any relation to the efficiency of the bean pod. We are now undergoing much the same challenging of ideas respecting the "points" of animals. These "points," by means of which the animals are "scored," are in large part merely arbitrary. Now, animals and plants are bred to the ideals expressed in these arbitrary points, by choosing for parents the individuals that score the highest. When it becomes necessary to recast our "scales of points," the whole course of evolution of domestic plants and animals is likely to be changed.

We are to breed not so much for merely new and striking characters that will enable us to name, describe and sell a "novelty," as to improve the performance along accustomed lines. We do not need new varieties of seedling potatoes so much as we need to improve, by means of selection, some of the varieties that we already possess. We are not to start with a variety, but with a plant. It is possible to secure a five per cent. increase in the efficiency of our field crops; this would mean the annual addition of hundreds of millions of dollars to the national gain.

The purpose, then, of our new plant-breeding is to produce plants that are more efficient for specific uses and specific regions. They are to be specially adapted. These efficiency-ideals are of six general categories:

1. Yield ideals.
2. Quality ideals.
3. Seasonal ideals.
4. Physical conformation ideals.
5. Regional adaptation ideals—as to climate, altitude, soil.
6. Resistant ideals—as to diseases and insects.

The main improvement and evolution of agriculture are going to come as the result of greater and better crop yield and greater and better animal production. It is not to come primarily from invention, good roads, rural telephone, legislation, discussion of economics. All these are merely aids. Increased crop and animal production are to come from two agencies: improvement in the care that they receive; improvement in the plants and animals themselves. In other words, the new agriculture is to be built upon the combined results of better cultivation and better breeding. So far as the new breeding is concerned, it is characterized by perfect definiteness of purpose and effort, the stripping away of all arbitrary and factitious standards, the absence of speculative theory and the insistence upon the great fact that every plant and animal has individuality.

CORNELL UNIVERSITY, ITHACA, N. Y.

THE CURTIS STEAM TURBINE.

BY W. L. R. EMMET.

(*Read April 2, 1903.*)

The development which this paper describes is based upon the original theories and inventions of Mr. C. G. Curtis, of New York, whose ideas were first made the subject of patent application about 1895. Since that time these inventions have been the subject of experimental investigation at Schenectady, under the direction of Mr. Curtis and of the General Electric Company's engineers; the object of these experiments being to establish data and laws which would form a basis for the correct design of commercial apparatus. The difficulties of such an investigation are very great. All new facts must be established by the tests of different machines or parts which are difficult and expensive to produce. About two years ago

the results of these experiments gave us data which showed great commercial possibilities, and since that time work has gone on on a large scale in the production of commercial machines. The contracts for these machines now aggregate 230,000 H. P. in turbine-driven electric generating units, the largest size so far built being 7500 H. P. Thus a great industry has been brought into existence in a very short time, and since the work has all been done in one place and by a few persons very little information concerning it has reached the public. This paper is the first printed matter which has appeared on the subject.

The reason for this immense demand and production, without publicity and in so short a time, is that the improvements effected are radical in economy, simplicity and efficiency of action.

All improvements in prime movers are of great importance to the engineering world. The steam turbine is destined to effect the first really great improvement since the days of Watt, and the forms of Curtis turbine here described make the first great stride in advance of other steam engines.

Every efficient steam engine must provide means by which a fair proportion of the expansive force of steam can be converted into useful work. In the engines of James Watt and his successors this result is accomplished in various degrees by the application of pressure from the steam to moving pistons. In steam turbines the expansive force imparts motion to the steam itself, and this motion is given up to a revolving part by impacts of the moving steam upon it.

The idea of the steam turbine is quite simple, and is similar to that of the water turbine or impulse wheel. The practical difficulty which has heretofore prevented the development of good steam turbines lies in the very high velocity which steam can impart to itself in expansion, and the difficulty in efficiently transferring this motion to wheels at speeds practicable for construction or practical use. Steam expanding from 150 pounds gauge pressure per square inch into the atmosphere is capable of imparting to itself a speed of 2950 feet per second, and if it is expanded from 150 pounds gauge pressure into a 28-inch vacuum it can attain a velocity of 4010 feet per second. The spouting velocity of water discharged from a nozzle with 100 feet head is 80 feet per second. These figures illustrate the very radical difference of condition between water turbines and steam turbines. In both water and steam tur-

bines the theoretical condition of maximum economy exists when the jet of fluid moves with a velocity equal to about twice that of the vane against which it acts. In water-wheels this relation is easily established under all conditions, while with steam the total power produces a velocity so high that the materials available for simple wheels and vanes are not capable of sustaining a proper speed relation to it under practicable conditions.

Before the appearance of the Curtis turbine two practical methods of accomplishing fair economy had been devised, namely, the turbines of Carl De Laval, of Sweden, and of Hon. Charles Algernon Parsons, of England, both of which were brought out more than fifteen years ago.

In the De Laval turbine the total power of the steam is devoted to the production of velocity in an expanding nozzle, which produces velocity very efficiently. The jet so produced is delivered against a set of vanes on a single wheel which, by an ingenious construction and method of suspension, is adapted to operation at a very high peripheral velocity. The very high rotative speed which this construction entails is made available for dynamo driving by very perfectly made spiral-cut gears which effect a ten-to-one speed reduction. The peripheral velocity of the wheel in the largest De Laval turbines is about 1200 feet per second, while the velocity which energy can impart to steam is over 4000 feet per second. Thus the wheel falls far short of the theoretically economical speed.

In the Parsons turbine the steam is carried in an axial direction through the space provided, between a succession of internal revolving cylinders and external stationary cylinders which enclose them. Both the internal and the external cylindrical surfaces are covered by many successive circles of vanes so arranged that the steam has to pass alternately through rows of moving and stationary vanes. In passing through this turbine the steam never acquires a speed which approaches the velocity which it attains in the De Laval nozzle; but instead moves along alternately, acquiring velocity by expansion, and partially giving it up by impact with the moving vanes.

Both of these turbines have attained some success, but neither, as thus far developed, affords sufficient advantage over the steam engine to cause any very rapid or radical change in engineering conditions.

The important disadvantages of the De Laval type are, that it is

limited by the imperfections of high-speed gearing, that its efficiency is not particularly high, and that the design is not conveniently applicable to large sizes. The Parsons type is principally limited by the multiplicity and weight of its parts, and the high cost of construction.

The Curtis turbine retains some of the features of its predecessors, but introduces new ideas which make possible a much lower speed, less weight, fewer and simpler parts, higher economy, less cost, and other important advantages.

The general arrangement of a turbine generating-unit of this type is shown by the drawings which accompany this paper. Its functions may be briefly described as follows, and are illustrated by the accompanying cut:

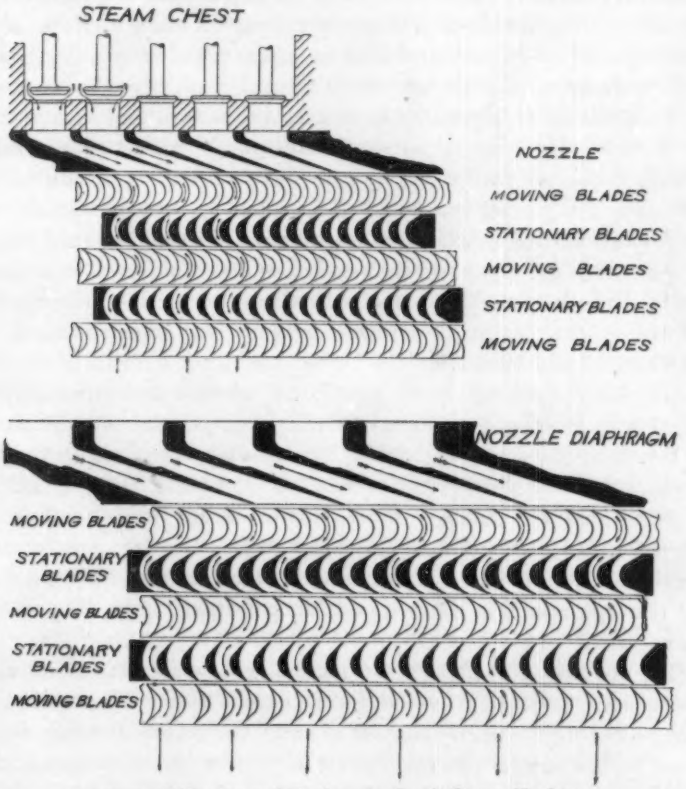


Diagram of Nozzles and Buckets in Curtis Steam Turbine.

Velocity is imparted to the steam in an expanding nozzle so designed as to efficiently convert nearly all the expansive force, between the pressure limits used, into velocity in the steam itself. After leaving the nozzle, the steam passes successively through two or more lines of vanes on the moving element, which are placed alternately with reversed vanes on the stationary element. In passing successively through these moving and stationary elements, the velocity acquired in the nozzle is fractionally abstracted, and largely given up to the moving element. Thus the steam is first thrown against the first set of vanes of the moving element, and then rebounds alternately from moving to stationary vanes until it is brought nearly to rest. By this means a high steam velocity is made to efficiently impart motion to a comparatively slowly moving element. The nozzle is generally made up of many sections adjacent to each other, so that the steam passes to the wheels in a broad belt when all nozzle sections are in flow.

This process of expansion in nozzle and subsequent abstraction of velocity by successive impacts with wheel vanes is generally repeated two or more times, the devices for each repetition being generally designated as a stage. There may be various numbers of stages and various numbers of lines of moving vanes in each stage. The number of stages and the number of lines of vanes in a stage are governed by the degree of expansion, the peripheral velocity which is desirable or practicable, and by various conditions of mechanical expediency.

Generally speaking, lower peripheral speeds entail more stages, more lines of vanes per stage, or both. Our general practice is to so divide up the steam expansion, that all stages handle about equal parts of the total power of the steam.

The losses and leakages of the earlier stages take the form of more heat or more steam for the later stages, and are thus in part regained. Much water of expansion, which might occasion loss by re-evaporation, is drained out of each stage into that which succeeds it.

The governing is effected by successive closing of nozzles and consequent narrowing of the active steam belt. The cut shows part of the nozzle open and part closed; the arrows showing space filled by live steam. In the process of governing, the nozzles of the later stages may or may not be opened and closed so as to maintain an adjustment proportional to that of the first stage, which is

always the primary source of governing. Some improvement of light-load economy may be effected by maintaining a relative adjustment of all nozzles; but in many cases the practical difference in economy is not great, and automatic adjustment of nozzle opening in later stages is dispensed with in the interest of simplicity. In some machines an approximate adjustment is maintained by valves in later stages, which open additional nozzles in response to increases of pressure behind them. These are used as much for limiting the pressures in stage chambers as for maintaining the light load economy.

The principle of the Curtis steam turbine is susceptible of application to a variety of purposes Within the scope of this paper I intend to give only a general idea concerning existing designs for its application to electric generators. Its development, even for this purpose, is very recent, and will doubtless be subject to important future improvements. In its present state, however, it embodies many important advantages, as has already been stated. The most important of these advantages is the high steam economy which it affords under average conditions of service. This economy is shown by the accompanying curves, which are derived from actual tests of the first commercial machine of this type which was completed. This machine drives a dynamo of 600 Kw. capacity. The curves give its performance at a speed of 1500 R.P.M., which is a safe and practical speed for commercial operation, and which corresponds to a peripheral velocity of about 420 feet per second. The results, with superheat, given in these curves are not derived actually from tests of this turbine, but are plotted from data obtained on smaller turbines. They correspond to the results obtained on turbines of other types and are undoubtedly reliable.

Curve 1 shows the steam consumption of this machine in pounds per kilowatt-hour output at various loads and under the conditions stated, the lower curve giving the steam consumption at various loads with 150 degrees superheat.

Curve 2 shows the results which could be obtained from this turbine if it were operated with high pressure and a high degree of superheat, these conditions of operation being perfectly practical with the machine, while with steam engines the use of such high temperatures would with ordinary constructions be prohibitive.

The results shown by these curves are better than any heretofore produced by steam turbines of any make or size, and are very much

better than those obtainable from the types of steam engines generally applied to the production of electricity.

It should be noted that these curves show a very high efficiency at light loads, as compared with results obtainable from steam engines, and that the efficiency does not fall off at overload, as it must necessarily do with all engines which operate economically under normal full-load conditions. This light-load and overload economy is an important feature of the Curtis turbine, and arises from the fact that the functions of its working parts is virtually the same under all conditions of load.

Curves 3, 4 and 5 show the effect upon steam consumption of changes in the steam pressure, the degrees of superheat and in the vacuum. It will be observed that the superheat and vacuum curves are straight lines so inclined as to indicate a great advantage by the use of all degrees of superheat and also an immense advantage in the use of very high vacuum. The most important reason why the Curtis turbine so greatly surpasses the steam engine in economy is that it is adapted to use effectively the highest possible degrees of expansion, while in the steam engine it is practically impossible to provide for high degrees of expansion. As the exhaust pressure approaches a perfect vacuum, the volume naturally increases at a rapid rate—the volume of steam with a 29″ vacuum being double that with a 28″ vacuum. To handle high degrees of expansion, it would, therefore, be necessary to make cylinders of steam engines very large, and this increase of size and weight of parts fixes a practical limit which cannot be passed without excessive cost and complication. In the turbine, the highest degrees of steam expansion are easily provided for, and consequently a much larger proportion of the total work in steam can be utilized by turbines than by steam engines.

There are other conditions in the Curtis turbine which make high degrees of vacuum more easily attainable than they are under ordinary conditions. The machine is so constructed that leakage of air into the vacuum chamber is easily rendered impossible. The leakage of air into condensing engines is considerable, and is generally not checked owing to the small value of improved vacuum to an engine.

With turbines of the type here described, no oil comes into contact with the steam, and consequently condensed water can be taken from surface condensers and returned to boilers. The use of

surface condensers under such conditions renders unnecessary the introduction of air either in feed or circulating water, and consequently makes possible a very high vacuum with small air-pumping apparatus.

The results shown by these curves are obtained from a machine of 600 Kw. capacity, and are naturally inferior to results which are expected from the very large units which are now being built. It is hoped that very soon after the reading of this paper a 5000 Kw. unit, which is now complete, will be put into operation in Chicago. This machine is expected to give considerably better steam economies than are shown by the accompanying curves, and will be superior particularly in the matter of light-load performance. The variation of efficiency in this machine from half load to fifty per cent. overload will not exceed three per cent.

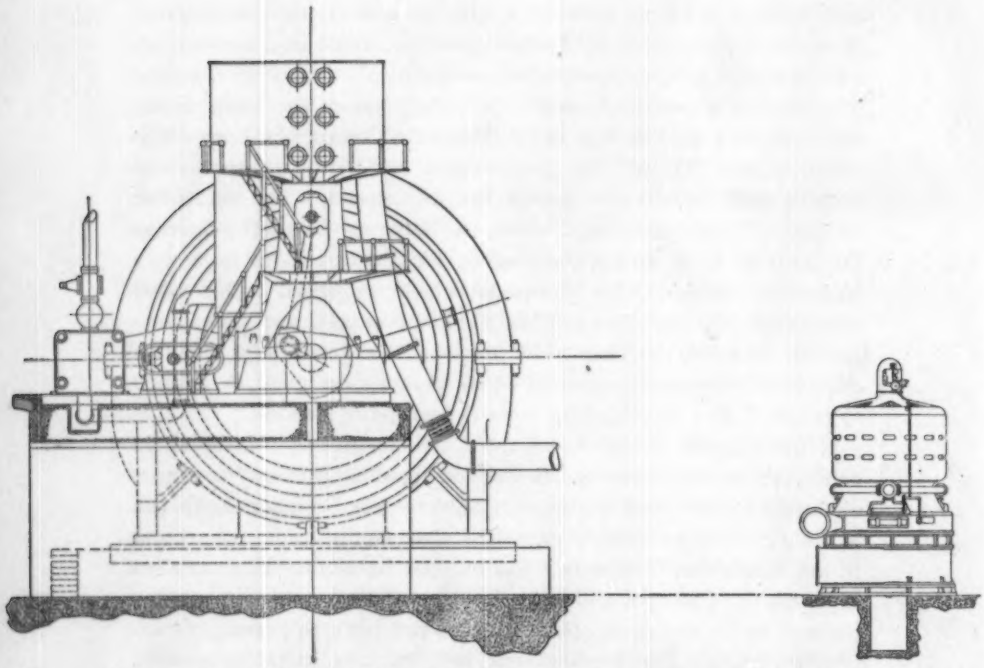
The external appearance and dimensions of this 5000 Kw. unit are shown by one of the drawings which accompany this paper, and another drawing shows this unit compared with an engine-driven generating unit of similar capacity. Each unit is shown as complete with prime mover and generator, one being the machine for Chicago, above mentioned; the other, one of the units which are operating in the Manhattan Railway Company's Power Station at New York. The comparison sufficiently illustrates the improvement which the turbine has introduced. The respective weights of these completed units, exclusive of foundation, are in the ratio of 1 : 8, and the saving in foundations alone is a very important item. Other drawings which accompany this paper show a 500 Kw. unit recently installed at Newport, and also a comparison drawn to the same scale between this 500 Kw. unit and a cross compound engine unit of equal capacity designed to operate at 100 R.P.M. The contrast here is even more striking.

If the extreme simplicity of the Curtis turbine is considered in combination with these figures and comparisons, it is easy to appreciate that a very great engineering advance has been accomplished. It has been conservatively estimated that engine units, like those in the Manhattan Company's station, can be replaced by turbines like that in Chicago, and that the cost of such replacement can be paid for by saving in operating expenses in three years.

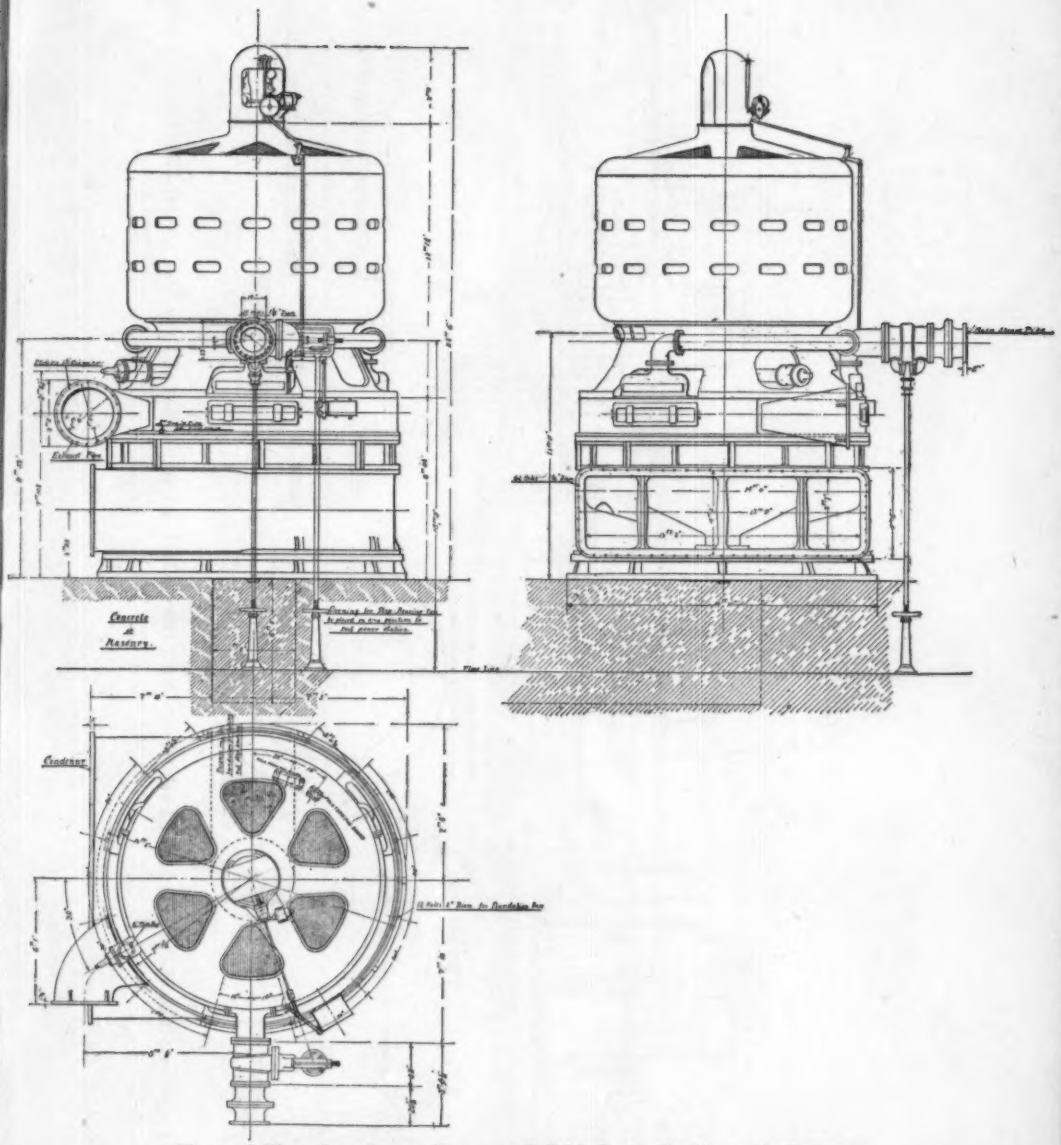
Whenever an improvement has been effected in prime movers, the influence upon engineering and business conditions has been very marked. When the release cut-off principle was introduced

by Corliss, a certain improvement in engine economy was effected, and although this improvement was accompanied by no diminution in cost, the change resulted in a very great activity in engine building, and the renewal of most of the large mill engines in the country. It is, therefore, safe to predict that the influence of the steam turbine will be of radical importance. The steam turbine is, on account of its high speed, particularly adapted to the driving of electric generators, and its introduction will consequently stimulate the use of electricity rather than other power transmitters.

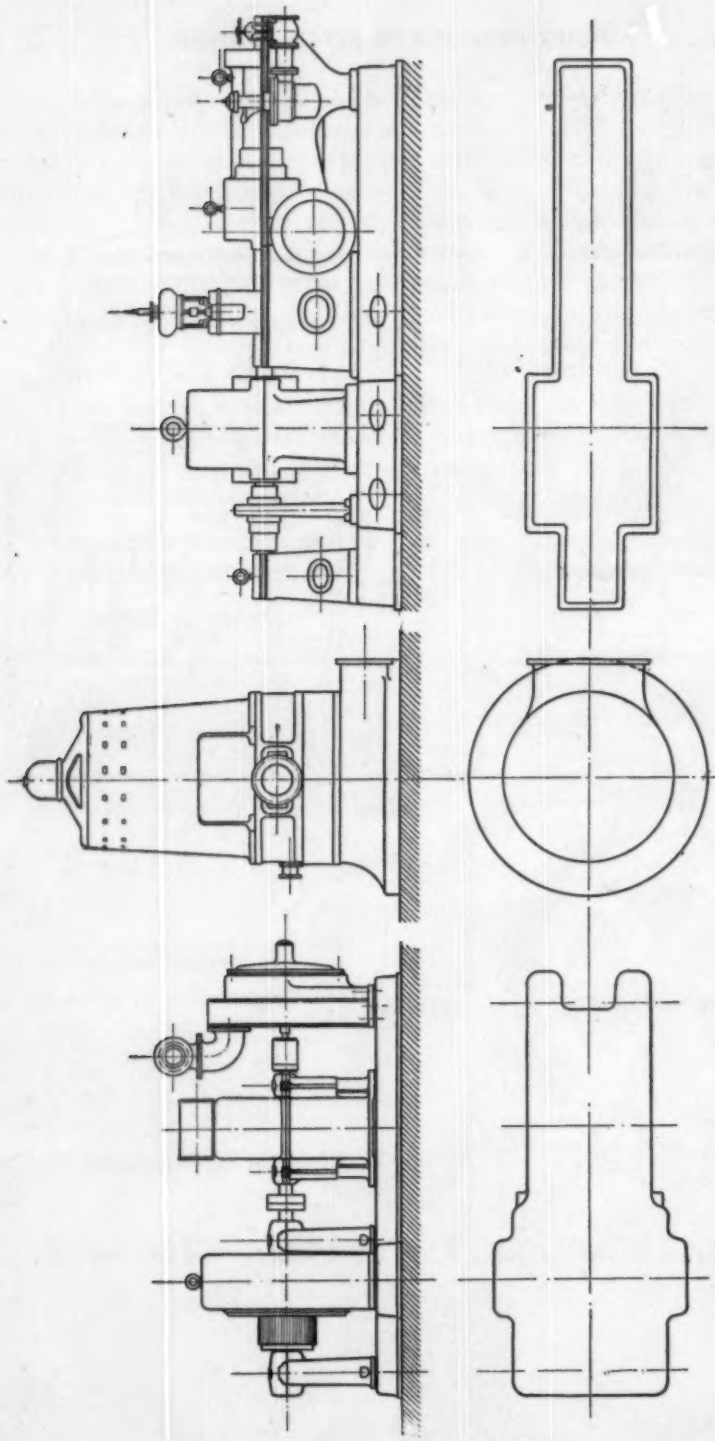
In the past the most economical use of steam has been confined to the most expensive and elaborate plants, while in the future it will be within the reach of all where condensing water is available.



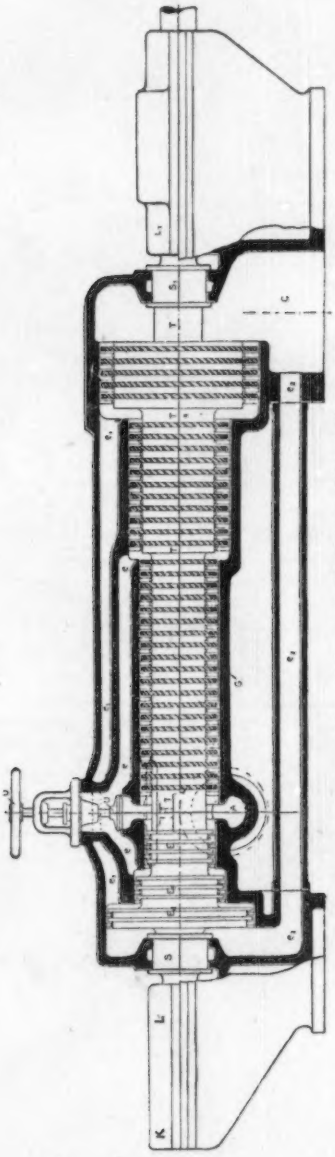
Comparative sizes of 5000 Kw., 75 R.P.M. Corliss Engine and 5000 Kw., 500 R.P.M. Curtis Turbine.



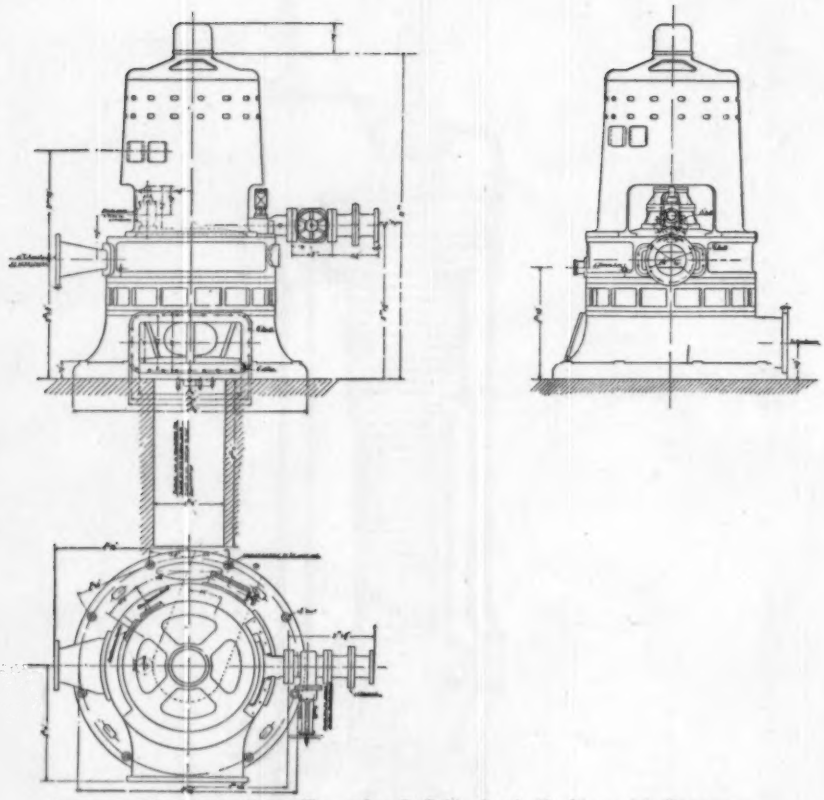
Plan and Elevation of 5000 Kw., 500 R.P.M. Curtis Turbine with Generator.



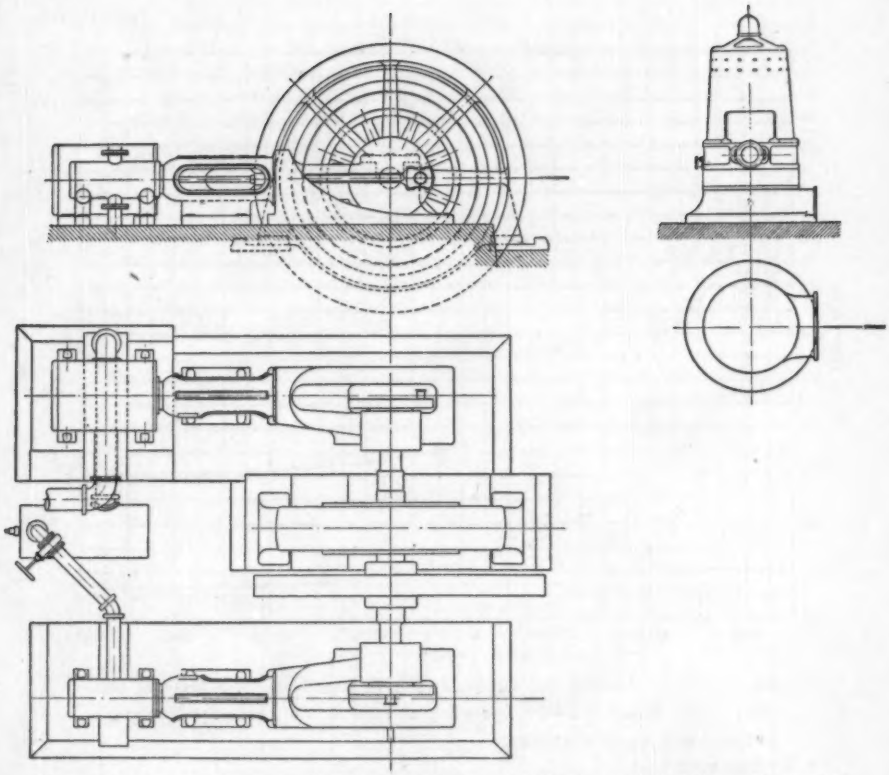
Comparison of 200 Kw., 9000 R.P.M. De Laval Turbine, 500 Kw., 1800 R.P.M. Curtis Turbine and 375 Kw., 3600 R.P.M. Parsons Turbine.



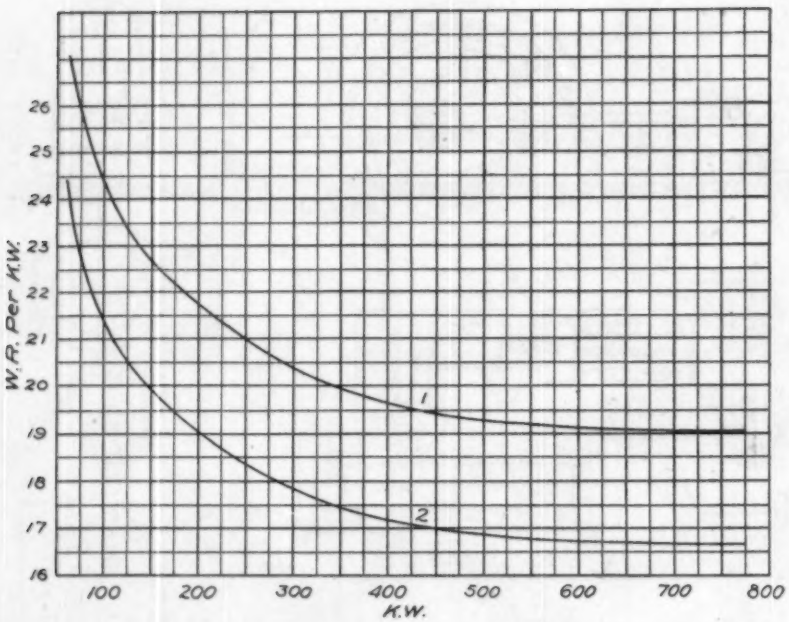
Cross-section of Parsons Turbine without Generator.



Plan and Elevation of 500 Kw., 1800 R.P.M. Curtis Turbine with Generator.



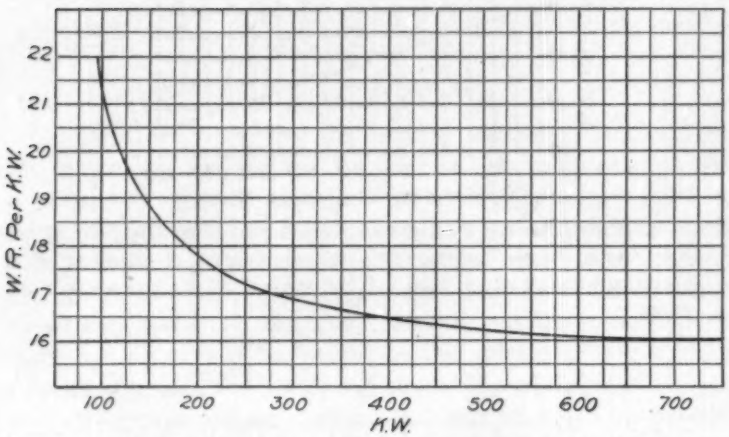
Comparison of 500 Kw., 100 R.P.M. Cross-compound Engine and 500 Kw., 1800 R.P.M. Curtis Turbine.



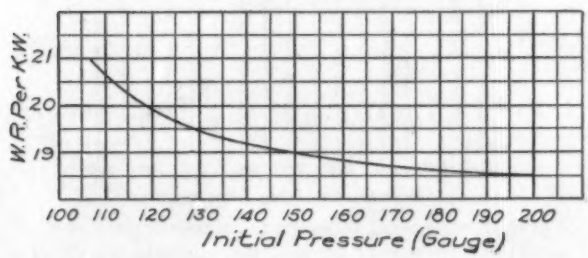
CURVE 1.—Curve showing water consumption, in pounds per Kw. hour, of 600 Kw. Curtis Steam Turbine, operating at 1500 R.P.M., with 140 lbs. gauge pressure and 28.5″ of vacuum.

1 Without superheat.

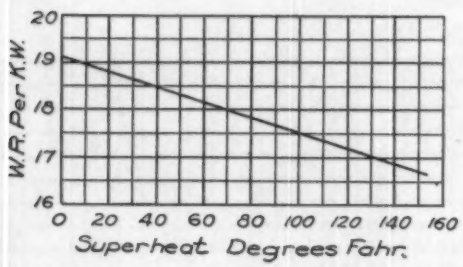
2 With 150° F. superheat.



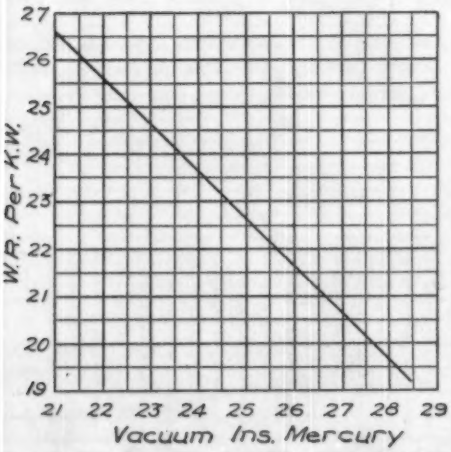
CURVE 2.—Curve showing water consumption, in pounds per Kw. hour, of 600 Kw. Curtis Steam Turbine, with different loads; speed 1500 R.P.M.; vacuum 28.5″; pressure 200 lbs. gauge, with 150° F. superheat.



CURVE 3.—Curve showing water consumption, in pounds per Kw. hour, of 600 Kw. Curtis Steam Turbine, at full load with different initial pressures; speed 1500 R.P.M.; vacuum 28.5″.



CURVE 4.—Curve showing water consumption, in pounds per Kw. hour, of 600 Kw. Curtis Steam Turbine, with different degrees of superheat when operating with full load at 1500 R.P.M.; vacuum 28.5″; pressure 140 lbs. gauge.



CURVE 5.—Curve showing water consumption, in pounds per Kw. hour, of 600 Kw. Curtis Steam Turbine, at full load with different degrees of vacuum; speed 1500 R.P.M; steam pressure 140 lbs. gauge.

SCHENECTADY, N. Y., APRIL 2, 1903.

NEW APPLICATIONS OF MACLAURIN'S SERIES IN THE SOLUTION OF EQUATIONS AND IN THE EXPANSION OF FUNCTIONS.

BY P. A. LAMBERT.

(*Read April 3, 1903.*)

I.—INTRODUCTION.

The modern theory of differential equations is based on the expansion by Maclaurin's series of the solutions of the equations in infinite series. The striking analogy existing between the theory of algebraic equations and the theory of differential equations suggested the possibility of expressing the solutions of algebraic equations in series to be obtained by an application of Maclaurin's series. After some experimenting the author happened on the device of introducing a factor x into all the terms but two of the equation $f(y)=0$, whereby y becomes an implicit function of x. The successive x-derivatives of y are now formed, and together with y are evaluated for $x=0$. By Maclaurin's series the expansions of y in powers of x become known. If x be made unity in these expansions, the roots of $f(y)=0$ are found, provided the resulting series are convergent.

To illustrate this method, consider the equation

$$(1)\quad y^4-3y^2+75y-10000=0.$$

Maclaurin's series

$$y=y_0+\frac{dy_0}{dx_0}x+\frac{d^2y_0}{dx_0^2}\frac{x^2}{2!}+\frac{d^3y_0}{dx_0^3}\frac{x^3}{3!}+\frac{d^4y_0}{dx_0^4}\frac{x^4}{4!}+\cdots,$$

where $y_0, \frac{dy_0}{dx_0}, \frac{d^2y_0}{dx_0^2}, \frac{dy^3_0}{dx_0^3}, \frac{d^4y_0}{dx_0^4}, \ldots$ stand for the values of $y, \frac{dy}{dx}, \frac{d^2y}{dx^2}, \frac{d^3y}{dx^3}, \frac{d^4y}{dx^4}, \ldots$ when x is made zero, expands y, a function of x, in powers of x.

By introducing a factor x in the second and third terms of (1) an equation is formed

$$(2)\quad y^4-3xy^2+75xy-10000=0$$

which defines y as an implicit function of x.

Differentiating (2) twice in succession

$$(3)\quad 4y^3\frac{dy}{dx}-3y^2+75y-6xy\frac{dy}{dx}+75x\frac{dy}{dx}=0$$

$$(4)\quad 4y^3\frac{d^2y}{dy^2}+12y^2\left(\frac{dy}{dx}\right)^2-12y\frac{dy}{dx}+150\frac{dy}{dx}-6x\left(\frac{dy}{dx}\right)^2-$$

$$6xy\frac{d^2y}{dx^2}+75x\frac{d^2y}{dx^2}=0.$$

Making x zero in (2), (3) and (4)

$$y_0=+\quad 10,-10,\quad +10\sqrt{-1}.\qquad -10\sqrt{-1}$$

$$\frac{dy_0}{dx_0}=-.1125,-.2625,+.\quad 1875-.075\sqrt{-1},+.1875+\ .075\sqrt{-1}$$

$$\frac{d^2y_0}{dx_0^2}=-.0029,-.0029,-.0000015+.0039\sqrt{-1},-.0000015-.0039\sqrt{-1}.$$

Substituting these four sets of values in Maclaurin's series and placing $x=1$, the roots of equation (1) are found to be

$$y_1=+9.886,\ y_2=-10.261,\ y_3=+.1875+9.927\sqrt{-1},$$
$$y_4=+.1875-9.927\sqrt{-1},$$

all correct to the last decimal.

This method will be applied to the solution (II) of trinomial algebraic equations, (III) of general algebraic equations, (IV) of trinomial transcendental equations, and finally (V) the method will be applied to obtain expansions commonly obtained by Lagrange's series.

II.—Trinomial Algebraic Equations.

The general trinomial equation of degree n has the form

$$(1)\quad y^n-nay^{n-k}-b=0.$$

Introducing a factor x in the second term of (1)

$$(2)\quad y^n-naxy^{n-k}-b=0.$$

Applying the method and denoting the n^{th} root of b by ω

$$(3)\quad y=\omega+\omega^{1-k}a+\omega^{1-2k}(1-2k+n)\frac{a^2}{2!}$$
$$+\omega^{1-3k}(1-3k+n)(1-3k+2n)\frac{a^3}{3!}$$
$$+\omega^{1-4k}(1-4k+n)(1-4k+2n)(1-4k+3n)\frac{a^4}{4!}+\ldots.$$

To determine when series (3) is convergent, group the terms numbered $1, n+1, 2n+1, 3n+1, \ldots$, then those numbered $2, n+2, 2n+2, 3n+2, \ldots$, finally those numbered $n, 2n, 3n, 4n, \ldots$. Each of these n partial series is found by Cauchy's ratio test to be convergent when a^n is numerically less than $k^{-k}(n-k)^{k-n}b^k$. When this condition of convergency is satisfied series (3), by substituting for ω in succession each of the n values of the n^{th} root of b, determines the n roots of equation (1).

By introducing the factor x in the third term of equation (1) and applying the method a series is obtained which determines k roots of equation (1), and by introducing the factor x in the first term of equation (1) a series is obtained which determines $n-k$ roots of equation (1). The two series thus obtained are convergent when a^n is numerically greater than $k^{-k}(n-k)^{k-n}b^k$. When $a^n=k^{-k}(n-k)^{k-n}b^k$ equation (1) has equal roots. There is therefore developed a complete theory of trinomial equations.

The general fifth degree equation can, by Tschirnhausen transformations requiring the solution of equations of the second and third degrees only, be transformed into the trinomial equation $y^5+ay+b=0$. If a^5 is numerically less than $\frac{625}{256}b^4$, the five roots of this equation are found by applying the method to $y^5+axy+b=0$. If a^5 is numerically greater than $\frac{625}{256}b^4$, the five roots are found by applying the method to $y^5+ay+bx=0$ and $xy^5+ay+b=0$. If a^5 numerically equals $\frac{625}{256}b^4$, the fifth degree equation has equal roots, and the removal of the equal roots makes the solution of the fifth degree equation depend on the solution of an equation of a degree not higher than the third. A third degree equation becomes trinomial by removing the second term, which is accomplished by a linear transformation. The method of this paper therefore effects the complete solution of the general fifth degree equation in infinite series.

In Weber's Algebra, volume I, pages 396–399, the real and imaginary roots of the equation $x^3-2x-2=0$ are computed by a method invented by Gauss for the solution of trinomial

equations. The convergency test shows that the series found by introducing the variable factor in the second term is convergent. Now the mathematician is satisfied when the convergency of the infinite series he uses is established, but the computer desires that the infinite series he is obliged to use shall converge rapidly. By transforming the equation $x^3 - 2x - 2 = 0$ into another lacking the first power, which is accomplished by placing $x = \frac{3}{3y-1}$, the equation $54y^3 - 18y - 23 = 0$ is found. The series found by applying the method to $54y^3 - 18xy - 23 = 0$ converges much more rapidly than the series obtained from the original equation. Differentiating $54y^3 - 18xy - 23 = 0$ four times in succession and making x zero,

$$y_0 = .7524, -.3762 \pm .3762\sqrt{-3}$$

$$\frac{dy_0}{dx_0} = .1477, -.0738 \mp .0738\sqrt{-3}$$

$$\frac{1}{2!}\frac{d^2y_0}{dx_0^2} = 0, \quad 0$$

$$\frac{1}{3!}\frac{d^3y_0}{dx_0^3} = -.0019, +.0010 \mp .0010\sqrt{-3}$$

$$\frac{1}{4!}\frac{d^4y_0}{dx_0^4} = .0004, -.0002 \mp .0002\sqrt{-3}.$$

The three values of y are .889 and $-.4492 \pm .3012\sqrt{-3}$, the corresponding values of x are 1.768 and $-.8847 \mp .5898\sqrt{-1}$. If the computations are made by logarithms they are not very lengthy.

The equation $y^4 - 11727\,y + 40385 = 0$ occurs in a paper by Mr. G. H. Darwin "On the Precession of a Viscous Spheroid," published in the *Philosophical Transactions of the Royal Society*, Part II, 1879, page 508. The convergency test shows that the factor x must be introduced in the last and in the first terms. The equation therefore has two real positive and two imaginary roots. Applying the method to

$$y^4 - 11727y + 40385x = 0,$$

$$y_0 = \quad 22.720, \quad -11.360 \pm 11.360\sqrt{-3}$$

$$\frac{dy_0}{dx^0} = -\ 1.148, \quad -\ 1.148$$

$$\frac{1}{2!}\frac{d^2y_0}{dx_0^2} = -\ .116, \qquad .058 \pm \ .058\sqrt{-3}$$

$$\frac{1}{3!}\frac{d^3y_0}{dx_0^3} = -\ .019, \qquad .010 \mp \ .010\sqrt{-3}$$

$$\frac{1}{4!}\frac{d^4y_0}{dx_0^4} = -\ .004, \quad -\ .004$$

Three roots of the equation are 21.432 and $12.444 \pm 19.759\sqrt{-1}$. Applying the method to

$$xy^4 - 11727y + 40385 = 0,$$

$$y_0 = 3.4436, \frac{dy_0}{dx_0} = .0120, \tfrac{1}{2}\frac{d^2y_0}{dx_0} = .0002.$$

The fourth root of the equation is 3.4558.

This method applied to trinomial equations proves that an equation of degree n has n roots, determines how many roots are real, and presents a uniform scheme for computing all the roots, real and imaginary.

III.—General Algebraic Equations.

The method applied to the complete equation of degree n furnishes $\frac{n(n-1)}{1.2}$ series, and it becomes necessary to determine which of these series give n convergent series for the roots of the equation and if possible to insure rapidity of convergence of these n series.

Suppose the equation of degree n to be

$$\underline{ay^n} + a_0y^{n-1} + \ldots + a_k y^{n-k+1} + \underline{by^{n-k}} + b_0y^{n-k-1} + \ldots$$
$$+ b_1y^{n-k-l+1} + \underline{cy^{n-k-l}} + c_0y^{n-k-l-1} + \ldots + c_my^{n-k-l-m+1}$$
$$+ \underline{dy^{n-k-l-m}} + d_0y^{n-k-l-m-1} + \ldots + ry + \underline{s} = 0,$$

and suppose the terms which are underscored to be the terms from which the two terms into which the factor x is not introduced must be selected by taking consecutive terms in regular order from the left. The problem is how to recognize the terms which must be underscored.

If the factor x is omitted from the first two underscored terms $y_0=\left(-\frac{b}{a}\right)^{\frac{1}{k}}$; if from the second and third underscored terms $y_0=\left(-\frac{c}{b}\right)^{\frac{1}{l}}$; if from the third and fourth underscored terms $y_0=\left(-\frac{d}{c}\right)^{\frac{1}{m}}$; if from the last two underscored terms $y_0=\left(-\frac{s}{d}\right)^{\frac{1}{n-k-l-m}}$. Altogether n values of y_0 are found, and it is seen at a glance what values of y_0 are real and what are imaginary. In order that these values of y_0 shall be close approximations of the roots of the given equation, the successive derivatives $\frac{dy_0}{dx_0}$, $\frac{d^2y_0}{dx_0^2}$, $\frac{d^3y_0}{dx_0^3}$, $\frac{d^4y_0}{dx_0^4}$, ... must be small. Forming $\frac{dy_0}{dx_0}$ corresponding to $y_0=\left(-\frac{b}{a}\right)^{\frac{1}{k}}$ and assuming that c is of such a magnitude that the term containing c overshadows all the other terms in the numerator of $\frac{dy_0}{dx_0}$, it is found that $\frac{dy_0}{dx_0}$ is necessarily small if the ratio of b^{k+1} to a^lc^k is numerically large. This same condition insures that the following derivatives $\frac{d^2y_0}{dx_0^2}$, $\frac{d^3y_0}{dx_0^3}$, ... are small.

In like manner it is shown that the derivatives corresponding to $y_0=\left(-\frac{c}{b}\right)^{\frac{1}{l}}$ are small provided the ratio of c^{l+m} to b^md^l is numerically large, and that the derivatives corresponding to $y_0=\left(-\frac{d}{c}\right)^{\frac{1}{m}}$ are small provided the ratio of d^{n-k-l} to $c^ms^{n-k-l-m}$ is numerically large. This ratio should, if possible, be made larger than 10 to insure rapid convergence.

The directions for underscoring terms are therefore as follows:

Underscore the first and last terms of the equation. Such other terms are to be underscored as satisfy the condition that if any three consecutive underscored terms be chosen, the ratio of the coefficient of the middle term with an ex-

ponent equal to the difference of the degrees of the first and third terms to the product of the coefficient of the first of the three terms with an exponent equal to the difference of the degrees of the second and third terms and the coefficient of the third term with an exponent equal to the difference of the degrees of the first and second terms shall be a large number.

To illustrate the method, the following equations are discussed:

$$(a)\quad \underline{y^5} - \underline{10y^3} + \underline{6y} + \underline{1} = 0.$$

Here all the terms are underscored, for the ratio of 10^4 to 6^2 is large, and the ratio of 6^3 to 10 is large. The method must be applied to (1) $y^5 - 10y^2 + 6xy + x = 0$, (2) $xy^5 - 10y^3 + 6y + x = 0$ and (3) $xy^5 - 10xy^3 + 6y + 1 = 0$. The computation determines the following values:

From (1)
$$y_0 = +3.167, \quad -3.167$$
$$\frac{dy_0}{dx_0} = -0.100, \quad +0.090$$
$$\tfrac{1}{2}\frac{d^2y_0}{dx_0^2} = -0.008, \quad +0.008;$$

From (2)
$$y_0 = +0.775, \quad -0.775$$
$$\frac{dy_0}{dx_0} = +0.107, \quad +0.060$$
$$\tfrac{1}{2}\frac{d^2y_0}{dx_0^2} = -0.006, \quad +0.016;$$

From (3)
$$y_0 = +0.166, \quad \frac{dy_0}{dx_0} = -0.007.$$

The roots of the given equation are $y_1 = +3.05$, $y_2 = -3.06$, $y_3 = +0.87$, $y_4 = -0.69$, $y_5 = -0.17$.

$$(b)\quad x^4 + 4x^3 - 4x^2 - 11x + 4 = 0.$$

Here the terms to be underscored in addition to the first and last are probably the second and fourth, but as the ratio of 4^3 to 11 is rather small, it is safer to transform the equation into another lacking the second term by the substitution $x = y - 1$. There results

$$\underline{y^4} - \underline{10y^2} + 5y + \underline{8} = 0.$$

The terms to be underscored are the first, second and last and the roots are obtained by applying the method to

$y^4 - 10y^2 + 5xy + 8x = 0$ and $xy^4 - 10y^2 + 5xy + 8 = 0$. From each of the two equations two real roots, one positive and one negative, are found.

$$(c) \quad 7x^4 + 20x^3 + 3x^2 - 16x - 8 = 0.$$

Here the terms to be underscored are probably the first, second and last, indicating the existence of two imaginary and two real roots, one positive and one negative. All doubt is removed by transforming by $x = y - .7$ into

$$\underline{7y^4} + .4y^3 - \underline{18.42y^2} - 1.404y - \underline{.5093} = 0.$$

The transformation $x = y - .7$ is selected because it is a simple transformation which makes the coefficient of the second term very small.

$$(d) \quad x^5 + 12x^4 + 59x^3 + 150x^2 + 201x - 207 = 0.$$

Here probably only the first and last terms are to be underscored, indicating the existence of four imaginary roots and one real positive root. Transforming by $x = y - 2$, which makes the coefficient of the second term small,

$$\underline{y^5} + 2y^4 + 3y^3 + 4y^2 + 5y - \underline{321} = 0.$$

The roots are found by applying the method to

$$y^5 + 2xy^4 + 3xy^3 + 4xy^2 + 5xy - 321 = 0$$

$$(e) \quad x^4 - 80x^3 + 1998x^2 - 14937x + 5000 = 0.$$

Here probably every term should be underscored, indicating four positive real roots. Transforming by the substitution $x = y + 20$,

$$y^4 - 402y^2 + 983y + 25460 = 0.$$

Here the terms to be underscored are the first, second and last. More rapidly convergent series are found by reversing the last equation,

$$25460v^4 + 983v^2 - 402v + 1 = 0,$$

and making the substitution $v = z - .01$, whence

$$\underline{25460z^4} - 35.4z^3 - \underline{416.214z^2} + 8.23306z + \underline{.9590716} = 0.$$

When z has been computed, x is found from

$$x = \frac{2000z + 80}{100z - 1}.$$

Only linear transformations which make the coefficient of the second term of the complete equation or of the equation reversed zero or small are used, as other transformations become too complicated to make the method practicable.

IV.—Transcendental Trinomial Equations.

Let an equation of the form $y+af(y)+b=0$, where $f(y)$ is a transcendental function, be called a transcendental trinomial equation. Such equations are readily solved by the method, provided the resulting series is rapidly convergent, but in the absence of a transformation which insures rapid convergence the method has little practical value.

Suppose the equation $2y+\log y - 1000=0$ to be given. Applying the method to $2y+x\log y - 1000=0$, if the Napierian logarithm of y is taken, $y_0=5000$, $\frac{dy_0}{dx_0} = -4.30625$, $\frac{1}{2}\frac{d^2y_0}{dx_0^2} = +0.000215$, and $y=4995.69$; if the common logarithm of y is taken, $y_0=5000$, $\frac{dy_0}{dx_0}=-1.84948$, $\frac{1}{2}\frac{d^2y_0}{dx_0^2} = +0.00018$, and $y=4998.15$.

V.—Expansions.

If $y=z+v\varphi(y)$, where v and z are independent variables, Lagrange's series expands any function of y in powers of v. These expansions may be obtained by writing $y=z+vx\varphi(y)$ and expanding $f(y)$, which now becomes a function of x, by Maclaurin's series and making x unity in the result.

The method will be illustrated by obtaining two expansions which occur in theoretical astronomy. From the equation $E=M+e\sin E$, where E is the eccentric anomaly, M the mean anomaly and e the eccentricity of the orbit, it is necessary to find E and $(1-e\cos E)^{-2}$.

To find E, write $E=M+ex\sin E$, whereby E becomes an implicit function of x. Differentiating twice in succession with respect to x,

$$\frac{dE}{dx} = e\sin E + ex\cos E\frac{dE}{dx},$$

$$\frac{d^2E}{dx^2} = 2e\cos E\frac{dE}{dx} + ex\cos E\frac{d^2E}{dx^2} - ex\sin E\left(\frac{dE}{dx}\right)^2.$$

Making x zero, $E_0 = M$, $\frac{dE_0}{dx_0} = e \sin M$, $\frac{d^2E_0}{dx_0^2} = 2e^2 \cos M \sin M$. Substituting in Maclaurin's series and making x unity,

$$E = M + e \sin M + \frac{e^2}{2} \sin (2M) + \ldots .$$

To find $(1 - e\cos E)^{-2}$, write $E = M + ex\sin E$ and $y = (1 - e \cos E)^{-2}$. Since y is a function of x through E,

$$\frac{dy}{dx} = -2e\,(1 - e\cos E)^{-3} \sin E \frac{dE}{dx}$$

$$\frac{d^2y}{dx^2} = 6e^2\,(1 - e\cos E)^{-4} \sin^2 E \frac{dE}{dx}$$

$$- 2e\,(1 - e\cos E)^{-3} \cos E \left(\frac{dE}{dx}\right)^2$$

$$- 2e\,(1 - e\cos E)^{-3} \sin E \frac{d^2E}{dx^2}$$

Placing $x = 0$, when $E = M$, $\frac{dE}{dx} = e \sin M$ and $\frac{d^2E}{dx^2} = 2e^2 \sin M \cos M$,

$$y_0 = (1 - e \cos M)^{-2},$$

$$\frac{dy_0}{dx_0} = -2e^2\,(1 - e \cos M)^{-3} \sin^2 M,$$

$$\frac{d^2y_0}{dx_0^2} = 6e^4\,(1 - e \cos M)^{-4} \sin^4 M,$$

$$- 6e^3\,(1 - e \cos M)^{-3} \sin^2 M \cos M.$$

Substituting in Maclaurin's series and making x unity,

$$(1 - e \cos E)^{-2} = (1 - e \cos M)^{-2} - 2e^2\,(1 - e \cos M)^{-3} \sin^2 M$$
$$+ 3e^4\,(1 - e \cos M)^{-4} \sin^4 M$$
$$- 3e^3\,(1 - e \cos M)^{-3} \sin^2 M \cos M + \ldots .$$

In like manner all expansions obtained by Lagrange's series may be obtained by a direct application of Maclaurin's series. Of course it is evident that if e is considered a variable the derivatives with respect to e may be formed and the introduction of x is unnecessary.

Historical Note.

Lagrange, in the memoir "Nouvelle methode pour resoudre les Equations Litterales par le moyen des Series," read before the Berlin Academy in 1770, found all the roots of an equation in infinite series. McClintock, in Volume xvii of the *American Journal of Mathematics*, obtained by his Calculus of Enlargement series better adapted to computation. It was recognized that these series may be obtained by Lagrange's series. McClintock calls the coefficients of the terms which have been underscored the dominants of the equation. The method of the present paper brings the computation of the roots of equations by means of series within the range of elementary instruction.

Since completing this paper the author found in an extract of a letter from Cauchy to Coriolis, of January 29, 1837, published in the *Comptes Rendus* of the Paris Academy, an announcement of important results to be obtained by breaking up an equation into two parts and introducing as a factor a parameter into one part, which parameter is ultimately to be made unity. In a postscript Cauchy states he discovered the advantage of making one part a binomial. But the author has been unable to find the method sketched in this letter developed. It would indeed be surprising if a method so strikingly direct had escaped notice.

Lehigh University, South Bethlehem, Pa.

ON THE PROPERTIES OF THE FIELD SURROUNDING A CROOKES TUBE.

BY ARTHUR W. GOODSPEED.

(Plates II and III.)

(*Read May 15, 1903.*)

The investigation of the subject implied by the title of this article was suggested by the unexpected presence on some radiographic records of peculiar markings outlining certain bodies *below* the plate, in addition to the expected shadows of the objects above the plate—*i.e.*, between the sensitive film and the vacuum tube.

While using an iron tripod stand with a ring-shaped top as a support for a radiographic plate, it was noticed that the plate when exposed to X-rays seemed to be influenced locally by the presence of the iron ring below. For after exposing a circular piece of bronze placed on the upper side of the plate which had rested on the stand during exposure, the development showed that just above the metal of the stand the plate was appreciably less affected through the bronze than under that portion of the latter which had not been over the metal support. This startling observation suggested at once more careful investigation, especially since on first thought it would seem that if the metal below the plate could have any effect, the result should be quite the contrary to what was observed—*i.e.*, if the metal below sends off "emanations" of some sort which might produce an effect on the sensitive film, the latter would be expected to show an increased density where influenced both by the rays from above and by the emanations from beneath.

Apparent anomalies have on several occasions been noticed on radiographic plates, some similar to that just mentioned, but these have never been definite enough to invite special investigation.

A large number of experiments were made at once in rapid succession with strips and plates of various substances both below and above the sensitive film, with results always the same in character though differing in intensity of effect in different experiments and with different materials. As examples of the character of some of the tests, sheets of paraffin, mica, and of aluminum were successively placed between the under metals and the film, with the result that the effect in every case was similar, only a little less intense

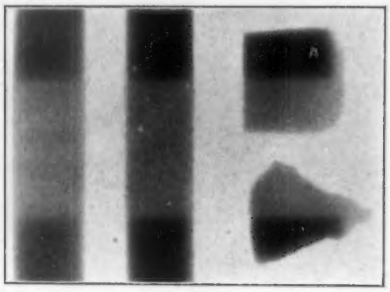


FIG. 1.

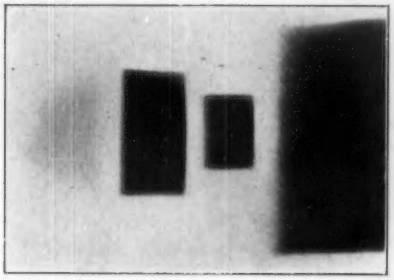


FIG. 4.

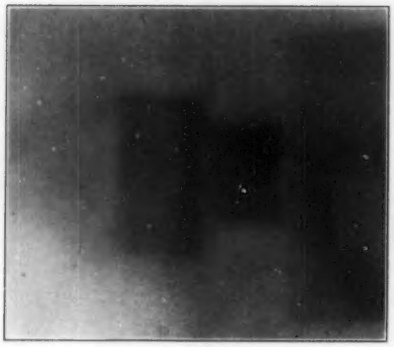


FIG. 2.

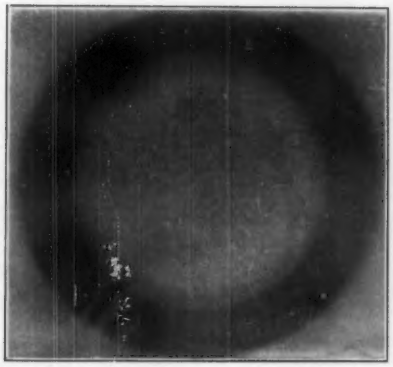


FIG. 5.

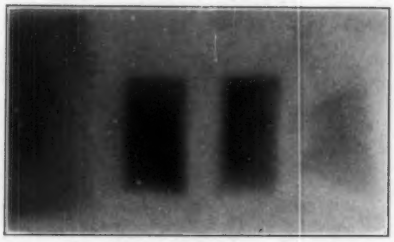


FIG. 3.

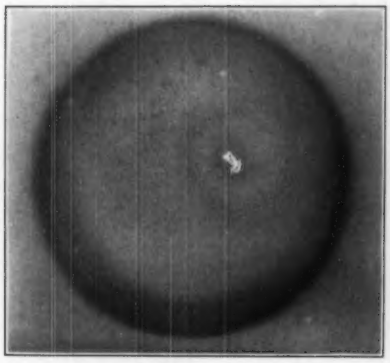


FIG. 6.

than when no screen was interposed. The original records of all these experiments and the particular conditions in each case have been carefully preserved. A single figure will be enough to illustrate this effect.

Fig. 1 shows the result when two zinc blocks, one of them polished, were placed below the photographic plate upon which the latter rested. On this were a strip of copper, one of lead, a triangular and thicker piece of uranium, and a piece of metallic indium about one millimetre thick and three centimetres square. Fifteen centimetres above this combination the discharge tube was operated for twenty-five minutes, the rays being directed downward. The zinc blocks were below the lateral edges of the plate and covered each about a third of its area. There certainly is nothing ambiguous about the result, and the degree of polish seems to have nothing to do with the effect. The middle third is distinctly darker than the rest in those parts just under the metal pieces.

The transverse strip in the middle was lead and is distinctly less pervious than the copper on the left.

In looking up some of the early work of Roentgen, I found that one of his experiments was almost identical in character with those just described, but less strenuous and designed for quite a different purpose.[1] He arranged star-shaped pieces of four metals, platinum, lead, zinc and aluminum, covered by a light-protected photographic plate, film towards the stars and glass towards the tube. On development after exposure to the rays from a focus tube identical in principle with that universally used at present, the metal stars showed darker than the rest of the ground. The purpose of his experiment was to demonstrate a possible reflection from the metal stars, and the result obtained was interpreted as conclusive evidence at the time that such was the case.

For obvious reasons it seemed desirable to repeat Roentgen's experiment as nearly as possible as he made it. This was done with some difficulty, on account of the fact that the apparatus in use developed rays of such penetrating power that the glass backing of the sensitive film offered little obstruction, and even with a very short exposure the whole film was so dense as to show nothing of the metal pieces.

Increasing the thickness of the glass made it possible, after several trials and by using a contrast-developer especially prepared for

over-exposures, to produce a fairly definite result, as shown in Fig. 2. It is to be noted, however, that the parts of the film just next the pieces are *less* dense than the rest—*i.e.*, the shadows are light on a darker ground.

Fig. 3 shows the result when to the glass of ordinary thickness was added thick blocks of zinc. The characteristics of these two plates are identical, except that the latter is more dense and shows greater contrast.

In Fig 4 we have reproduced a plate made just as was that of Fig. 3, except that the exposure was thirty minutes instead of fifteen. The appearance is certainly remarkable, for though the direct X-rays had been entirely cut off by the zinc blocks the shadows are exactly as would have been produced by reversing the process and exposing directly to the Roentgen rays, though for a much briefer time.

The influence on the side of the plate remote from the tube seems to have more than neutralized the Roentgen reflection effect, and the more so the greater the exposure.

From these three experiments it seems probable that with a much less powerful X-ray generator, a suitable exposure would show the result noted by Roentgen. As is seen below, this was probably not due to reflection.

The next plate (Fig. 5) shows the impression of the ring stand, above spoken of, when the former was covered with a sheet of copper about a millimetre thick and exposed twenty-four minutes. In Fig. 6 the stand is replaced by a brass ring supported by a block of wood. The penumbral effect around the inside edge is to be noted.

As an interesting modification of this experiment I asked one of my associates, Dr. Richards, to hold his hand beneath the plate, protected above with thick metal blocks, and exposed the combination five minutes. The result (see Fig. 7), though lacking in definition, is quite like the first radiographs made without a focus tube.

We seem now to be led up to a satisfactory explanation of what we have observed so far—*i.e.*, of this apparent "nether effect" reaching completely around into the shadow of an obstruction totally impervious to X-rays proper, and acting in a direction just opposite to that of the rays from the tube.

It must be noted here that so-called "X-ray diffusion" has long been recognized, and an early experiment[2] with a fluoroscope

behind a thick steel plate was explained variously, the most thoughtful suggestion perhaps being by Prof. Elihu Thomson, who proposed that the screen was rendered luminous by the action of X-rays reflected from various objects in the room.

From all the experiments yet made in the effort to account for what at first seemed to be, to say the least, a paradox of science, it looks as if the whole space field in the neighborhood of a focus Crookes tube in operation is full of some sort of subtle energy, radiant possibly, but incapable of affecting the human eye, though leaving its mark on a photographic plate.

It was found by Sagnac[3] that many bodies in the path of X-rays acquire the property of emitting emanations of some sort capable of causing fluorescence and photographic action.

Undoubtedly then the effects above described are due to the secondary radio-activity of the air, the table and other bodies favorably located to be impinged by the X-rays directly.

In order to gain more knowledge of the possible limitations of this "radious" field, metal tubes of various sizes and lengths were placed on the plate, and now for convenience the entire local order of the articles used was completely reversed. Furthermore, the Crookes tube *was enclosed in a black wooden light-tight box, and all experiments were made in the night, so that every trace of optical light might be more easily excluded.* We have now the tube in its box, so placed that the axis of the ray-cone is directed vertically upwards. On the upper surface of the box and over the focus of the tube is a bundle of lead plates about one centimetre thick. On this, film upward, is the photographic plate.

This arrangement differs from that of Sagnac in that the *fluorescent light* from his tube was not filtered out, as it is here, by the box enclosing the X-ray bulb.

In Fig. 8 we have the result of a twenty-three minute exposure, when a brass tube five centimetres high, eight centimetres in diameter and three millimetres thick is placed on the plate, the tube being open at the top. This experiment was repeated with a thick block of pine wood, placed on top of the brass tube, with no change in result. The condition of the enclosed space is independent of the presence of the wood, and the enclosed area of the film is much affected.

When however the tube is covered with a thick block of zinc, this seems to protect the sensitive film completely from outside

influence, for the density of the exposure was found to be the same over the area within as under the edge of the tube, *i.e.*, nearly zero.

It does not seem possible that this effect could result entirely from the action of the Sagnac rays, since little if any of the area at the base of the brass cylinders can be reached by a straight line from any particle of matter traversed by the direct X-rays. It can be explained as a tertiary effect, produced by the air or wood just over the top, which had received its energy from the secondary emanations of other bodies in the direct path of the X-rays, or possibly the secondary or Sagnac rays may be of the nature of dark phosphorescence, *i.e.*, lasting for a time after the cause has ceased. Reasons for favoring the latter view appear as a conclusion to this paper. In this case the diffusion of the air in the room would cause the whole space to be uniformly active.

The arrangement just described suggested some easy tests on reflecting or diffusing power of different surfaces, as Sagnac had made in a different way in his investigations. In a brass tube similar to the one used above, at two points 90° apart, windows were cut 1 centimetre wide and 4.5 centimetres high. This tube was capped with zinc or lead, so that nothing could enter except through the windows. It was placed on the plate and a polished zinc block arranged opposite one window. Fig. 9 shows the result, all other conditions being as before. The exposure was twenty minutes. The streak entering the window opposite the zinc is unmistakable, and the diffused "radious" state of the whole enclosed space is demonstrated by noting the line of contact of the tube. A little brush in at the other window, too, is clearly distinguishable though faint. It seemed most desirable now, if possible, to make this phenomenon optically visible, and with this in view the following arrangement was set up:

Instead of the smaller lead block used with the radiographic plates, sheets aggregating one centimetre in thickness and a little larger than a 7x9 screen were placed on the box. On this a barium platinum cyanide screen was placed, face up, but covered with a piece of pasteboard. In this cover a circular hole was cut just the outside diameter of the window tube described above, through which the latter was placed, resting on the fluorescent screen. Its length was doubled by placing an extension on top. This was found by experiment effectually to exclude all noticeable influence except that through the windows.

FIG. 7.

FIG. 8.

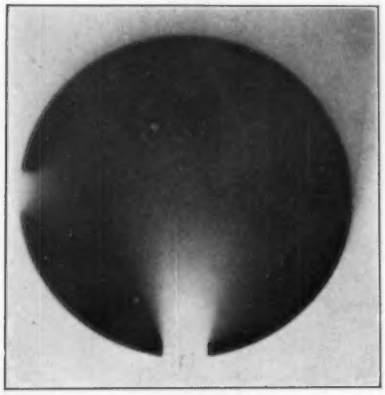


FIG. 9.

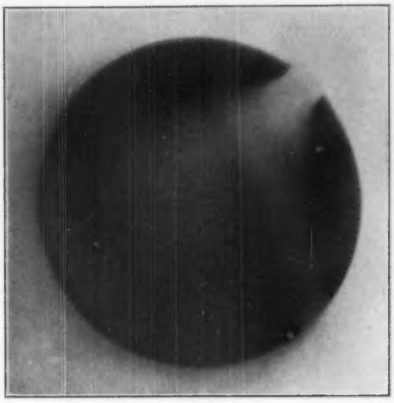


FIG. 10.

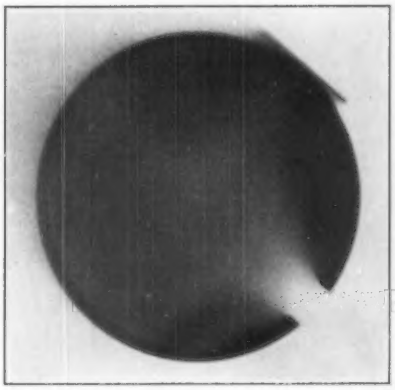


FIG. 11.

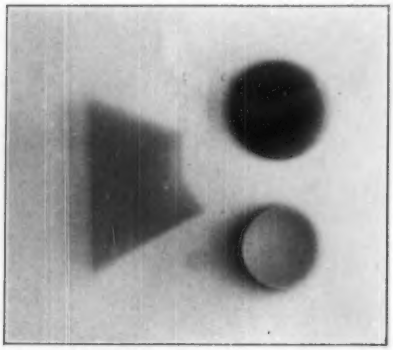


FIG. 12.

The whole was in a perfectly dark room optically, and the eye was placed above the tube looking down. After the eyes had acquired a maximum sensitiveness by the total exclusion of light for ten to fifteen minutes, the Crookes bulb was set in operation and the space within the brass tube critically examined from above. The screen was unmistakably luminous to the eye and the windows were clearly located. Now the polished zinc was moved about in front of one of the openings, in the hope of detecting a variation of luminosity on the screen opposite this window. The result was at first disappointing; the position of maximum effect was certainly not that of 45°, as employed in the photographic experiments. In fact, very inconsistent positions seemed to give the greater illumination through the window under attention. Finally it became quite obvious that the zinc had little to do with what was visible. In fact, on laying aside the metal I was able to light up brighter than ever the inside of the brass box by holding my hand in a suitable position in front of the window.

This experiment made certain by ocular demonstration that the human hand has by being placed in the path of the X-rays absorbed some sort of energy, by means of which it has acquired the property of emanating something capable of exciting fluorescence upon the screen. It remains now to demonstrate what effect these emanations will have upon a photographic plate as compared with those from the zinc, and Fig. 10 shows the result of a three-minute exposure with my hand only, placed opposite one of the windows, the tube resting upon a photographic plate in its usual protecting envelopes. A similar experiment was next tried (see Fig. 11) by holding a hand in front of each window, one of the latter being closed by a thin sheet of plate glass. It is obvious from the results obtained that the physiological rays emitted by the hands affect the plate through its protecting covers, but are unable easily to penetrate glass.

It is only a step now to produce a "physio-radiogram," and Fig. 12 is a reproduction of a record made by the secondary activity emanating from my own hand stimulated by a stream of Roentgen rays with an exposure of three minutes. The shadows are those of a cent, a gold finger-ring and a piece of aluminum about half a millimetre thick, and it is apparent that aluminum is somewhat translucent to these rays.

Although Guilloz[4] had made just such shadow radiographs with

Sagnac rays emanating from his hand, the visible fluorescence generated by the tube was not cut off by any opaque screen, and there is no reason for assuming that this light may not have played some part in his results. In the present experiments everything has been done in complete optical darkness.

I have been unable to find out if Guilloz's pictures were actually published, and so cannot compare his results in detail with my own.

In connection with the present subject, my attention has been called by unpleasant personal experience to a very suggestive coincidence. The nature and pathology of X-ray dermatitis is, and has been from the first, surrounded with mystery. Much ingenious technical literature has been published in the medical journals all over the world for the last six years, with the result that to-day little is known about either the real cause, the nature, the proper method of preventing, or the best treatment of this most distressing and lingering affliction. A comparative history of many cases reveals many inconsistencies, followed by an increased sense of ignorance on the subject. The personal experience to which I refer suggests a possible step towards a better understanding of the phenomenon.

During a week in June, 1902, I occupied the Roentgen ray room as a sleeping apartment. At the end of this time an acute inflammation of the eyes and throat appeared, all symptoms of an ordinary cold or of any digestive disturbance being absent. At the end of the week referred to I left town and the inflammation gradually subsided during the next three or four days. For similar reasons I had occasion to sleep in the same room during the first week of the present month. At the end of that time my attention was painfully called to a recurrence of the symptoms observed a year ago. On ceasing to sleep in the room all trouble disappeared.

As I have never had any such experiences other than those referred to, it seems not too much to infer that the peculiar inflammatory condition may have been due to some action of the secondary emanations sent out by the walls and air of the room after the generation of X-rays had ceased. Continuous breathing of such "darkly phosphorescing" air might well account for the trouble in the throat and vocal chords. In the daytime the doors and windows were always more or less open, so that the air was continuously changing, and my eyes were protected considerably by glasses, through which neither the primary nor the secondary rays pass easily.

The inference seems fair that the recurrence of the inflammatory condition was not a mere coincidence, and that these secondary rays may be found to be of more importance than has been supposed.

Bibliography.

[1] Thompson, *X-Rays*, p. 70.

[2] Thompson, *X-Rays*, p. 129.

[3] Sagnac, *Compte Rendus*, 1897–98. Sagnac, *Annales de Chemie et de Physique* (7), xxii, 1901; pp. 493–563. Perrin, *Compte Rendus*, Vol. cxxiv, p. 455. Townsend, J. S., *Proc. Camb. Philos. Soc.*, 1900, x, pp 217–226.

[4] Guilloz, *Compte Rendus*, February, 1900.

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May 15, 1903.